Age-Related Bone Loss And Osteoporosis In Archaeological Bone: A Study Of Two London Collections, Redcross Way and Farringdon Street.

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Abstract

This thesis examines the ways in which age- and sex-related bone loss in archaeological bone can be assessed, with a view to providing criteria by which osteoporosis should be diagnosed. Sample material for this investigation came from two London collections of skeletal material dated 1700-1850 (Redcross Way and Farringdon Street).

A comparative study using a wide range of techniques for the detection of bone loss was carried out on the samples from Redcross Way. Sample numbers were then increased through the inclusion of the material from Farringdon Street in order to provide sufficient data to examine changes seen in relation to age and sex.

Current research into bone biology and knowledge of osteoporosis in the present day population was reviewed in the context of possible observations that can be made on archaeological bone.

There is a large body of historical literature available relating to the period covered by this study (AD 1700-1850). A review was made of material relating to population demographics and medical literature relating to fractures. This work showed that it is valid to study osteoporosis in populations of this period, as a significant number of individuals reached an age at which today they could be considered at risk of sustaining an osteoporotic fracture. Literature relating to fractures contained significant numbers of reports of cases of fracture which, from knowledge of such fracture in the present population, fit the criteria of osteoporotic fractures.

Archaeological bone was examined using non-invasive investigative techniques many of which are in current clinical use for the determination of osteoporosis. These were: dual energy x-ray absorptiometry; low angle x-ray scattering; and optical densitometry. Optical densitometry was also applied to bone slices. Cortical bone was assessed through calculation of its area, and thickness. The cortical index were calculated from radiographs. Trabecular bone loss was assessed from femoral radiographs using the Singh index, and stereometric measurements made using close range photogrammetry.

The possibility of the archaeological bone material having undergone post-mortem (diagenetic) changes, which can adversely affect results obtained from non-invasive investigations, was briefly addressed. Mineral deposition was found to have occurred in some of the sample material examined.

It was found that the direct examination and measurement of the three dimensional trabecular architecture through stereometric analysis provided the best indication of bone loss and, possibly osteoporosis. Where sample material cannot be sectioned and non-invasive investigative techniques have to be applied, low angle x-ray scattering, which produces quantitative and qualitative measurements of trabecular bone, produced the most reliable results. Both these techniques overcame the problems associated with diagenetic change in archaeological material.

The results from the investigation of the Redcross way and Farringdon Street skeletal material showed that age- and sex-related bone loss was taking place, with loss occurring at an earlier age and being more severe in females than males. The conclusion is made that patterns of loss observed in the archaeological bone broadly mirror those seen in the present day population

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1. Introduction

Osteoporosis is currently a major health problem both economically and socially throughout North America, Europe and Oceania. Bone loss associated with the condition can lead to fracture, most commonly at the hip, wrist or spine. Such fractures can cause pain, disability and even death. Increasing awareness of the condition has led to the question, 'to what extent were past populations affected'? However, the impact that the condition may have had in the past is far from clear.

The aim of this project was to evaluate techniques available for the analysis of bone loss and osteoporosis in archaeological bone. Using the data obtained from these techniques, the broad pattern of bone loss and possible incidence of osteopenia and osteoporosis were assessed.

The region and period chosen to focus on in this project was London 1700-1850. In London there are sufficient sources of both historical material and archaeological bone material from this period to provide two possible lines of evidence for the present study. Archaeological material for this study came from the sites of Redcross Way and Farringdon Street, and historical material was obtained from institutions such as the library of the Wellcome Institute For The History of Medicine and the Royal College of Surgeons. Both archaeologists and historians constantly work against the limitations of their discipline. It was hoped that by using both lines of evidence a fuller picture of the situation would be gained. Great care has to be taken when trying to draw conclusions because of the problems inherent in using each type of source material.

Prior to the analysis of archaeological bone or historical research, a review of all aspects of current research into the condition was undertaken. Work published on bone biology, diagnostic techniques and treatments, as well as factors thought to cause or contribute to bone loss and osteoporosis are discussed. Such a review is important as it is only with a clear understanding of these aspects of the condition that a successful study of the detection and prevalence of bone loss and osteoporosis can be undertaken.

The knowledge gained in this study enabled an informed review of historical documents relating to fractures to be made. Documents such as death registers, relating to the sites from which the bones were obtained, enabled a review to be made of population demographics during this period. This review also informed the approach to the archaeological bone. The site material from Redcross Way was used to test a range of bone analysis methods. Assessment of archaeological bone fell into three main types: studies of density, trabecular bone structure and cortical bone. Four bone areas, the femoral neck the fourth lumbar vertebral body, the distal radius and the iliac crest, were used where available for each technique. Sample numbers were then increased using fourth lumbar vertebral bodies from Farringdon Street in order that the bone loss might be examined with respect to age and sex.

The relative usefulness of each technique, its availability and accuracy in detecting bone loss are discussed. The ease of use of each bone type studied and the results of a range of techniques tested are also considered. Problems associated with archaeological bone such as diagenetic change are briefly investigated.

From this study broad guidelines have been drawn up for the study of bone loss in archaeological bone and conclusions drawn about the pattern of bone loss and osteoporosis in the time period under study.

2. Background to the Condition of Osteoporosis

2.1 Introduction

In order for a meaningful study to be made of the techniques used for detecting osteoporosis and for determining its prevalence in past populations, the definition of the term and all the biological processes which operate in its onset and development leading to fracture must be understood. The sample material used in this study is from the comparatively recent past, and it is extremely unlikely that the biological processes involved in bone remodelling have altered since this period. Individuals will have been affected by similar processes to the present day population. As can be seen in the analysis of the demography of the populations under study (Section 6.3), individuals were reaching an age at which they could be considered to be at risk from osteoporosis. Major changes affecting life expectancy since the period covered by the present study will have been environmental factors, such as improvements in general health care.

2.2 What is Osteoporosis?

"Osteoporosis is a disease characterised by abnormalities in the amount and architectural arrangement of bone tissue that lead to impaired skeletal strength and an undue susceptibility to fracture" (Melton *et al.* 1992, p.15). This definition of osteoporosis provided by Melton and his co-workers is just one of many; all differ marginally in emphasis, but are basically the same. As Kanis (1994) pointed out, it is extremely hard to produce a clear definition for the condition, because all adults lose bone mass as they age (Section 2.3.3). There are still rapid advances being made in osteoporosis research, with new theories being advanced all the time (Section 3.0 and 2.3), but there is now a better understanding of the processes involved in the development of the condition, their causes and the course they take. The many different approaches to the study of osteoporosis emphasise its multifactorial nature. The term osteoporosis should only be used in cases of extreme osteopenia where natural bone loss has been exaggerated and the individual is liable to suffer from one of the associated fractures (Gallagher 1990). Osteoporosis itself has been divided into two main groups; primary and secondary, depending upon the causative factors involved. Primary osteoporosis includes Type I postmenopausal and Type II senile (Riggs and Melton 1983). Secondary osteoporosis is defined as being attributed to one known cause, such as disease or reaction to drugs (Section 3.3.7).

The term osteoporosis first appeared in the literature around 150 years ago, but has only taken on its present meaning in the last 50 years. Prior to this date it was used for numerous bone conditions, for example, osteomalacia and osteitis fibrosa cystica. The early definitions "merely indicate the literal meaning of the word (a porous bone)" (Schapira and Schapira 1992, p165).

2.3 Bone Biology

To fully understand the processes operating to produce osteoporotic fracture it is vital to have knowledge of the mechanisms involved in the formation and growth of bones, and changes within it throughout life. Advances in techniques available for the study of bone have led to a much broader though still incomplete understanding of bone biology, especially at the cellular level. Continuing research has revealed the complexity of processes taking place and the way in which these are regulated by physical and chemical conditions. Tetracycline labelling and bone biopsy are valuable tools in the gaining of this knowledge allowing the processes of bone remodelling to be studied (Eriksen *et al.* 1985).

An important feature of bone is that, despite its hardness, it is not a static tissue. Throughout the growth period in childhood and early adulthood there is massive change as bones increase in size. Even after an individual has reached maturity bone continues to be remodelled, adapting to changing patterns of stress. Like most tissues of the body bone is constantly renewed, and the continuous turnover of bones prevents damage to the structure due to fatigue and is important in maintaining calcium homeostasis (Peel and Eastell 1995). Factors producing changes can be physical, such as stresses resulting from taking part in manual labour, or sporting activity. Chemical factors may also cause change, for example responses to hormonal variation within the body such as levels of oestrogens in women (Section 3.3.2).

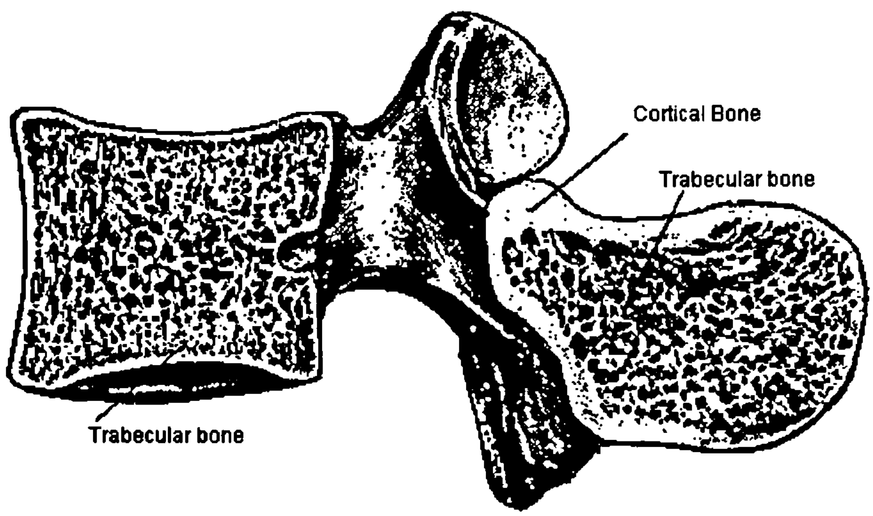


Figure 2.3.1 Section through a lumbar vertebral body, showing areas of both cortical and trabecular bone. After Soames (1995).

2.3.1 Bone Structure

As can be seen in Figure 2.3.1, the skeleton contains both trabecular and cortical bone. Trabecular bone makes up approximately 20% of the skeletal mass (Woolf and St John Dixon 1988), forming the main component of the vertebral bodies and the epiphyses of the long bones. There are also small amounts at other sites within the skeleton such as the iliac crest and diploë of the skull. Within these regions, trabeculae form a semi-rigid framework of bony struts, arranged so as to provide support to the structure of the bone in relation to the forces placed upon it. This framework, which has a high surface area, allows the bone to resist stresses caused by general movement or sudden impacts on the body such as those produced by a fall. In younger individuals, the spaces between the trabeculae are filled by red marrow, but in later life this is largely replaced by yellow bone marrow made up of fat and fibrous tissue. The areas of trabecular bone are enclosed within a thin layer of much denser cortical bone, which comprises approximately 80% of the mass of the human skeleton. Cortical bone is formed from Haversian systems, consisting of a central Haversian canal surrounded by a concentric arrangement of bone tissue (Sambrook *et al.* 1993). Such bone is found throughout the skeleton, for example in areas such as the skull and the diaphyses of the long bones.

2.3.2 Bone Remodelling

The continual remodelling of trabecular and cortical bone involves both bone formation and resorption. These processes are shown schematically in Figure 2.3.2 below. Osteoblasts and osteoclasts, the two major cell types involved in the remodelling, each have a different role. Bone formation is carried out by osteoblasts. Osteoblasts differentiate in an area where formation is to take place, and secrete the organic components of bone matrix, which is subsequently mineralised. Maturation can take place in lamella bone (the bone mostly involved in remodelling) over a period of months. Newly laid-down matrix can become fully mineralised, before entering a 'resting' phase during which it is covered by 'resting' osteoblasts, bone-lining cells. At some later date resorption may take place. The initiation or 'activation' of this process depends on retraction of the lining cells, that normally cover all bone surfaces (Dempster and Lindsay 1993, Heaney *et al.* 1987). Osteoclasts are cells which have the ability to resorb all mineralised tissues by bonding onto the bone and secreting protons and proteolytic enzymes (Arnett 1991). Areas of bone where resorption has taken place exhibit characteristic resorption pits or Howships lacunae. Both bone formation and resorption are continually in operation, and under normal circumstances in mature adults a dynamic equilibrium exists between them and the bone is in no way diminished. Turnover rate is widely quoted as being around 25% per annum in trabecular bone and 2-3% in cortical bone (Dempster and Lindsay 1993, p.798). Although figures such as these are mentioned in the literature no mention is made of the original work undertaken to determine such figures. There are calculations given by Parfitt (1976) which show cortical bone turnover to be around 2.5% per. annum. No precise figures were found for trabecular bone, but it is generally assumed to be more metabolically active (Dargent and Breart 1993). Peak bone mass is achieved in early adulthood, after which there is a generalised loss of bone mass, occurring throughout the skeleton (Mazess 1982).

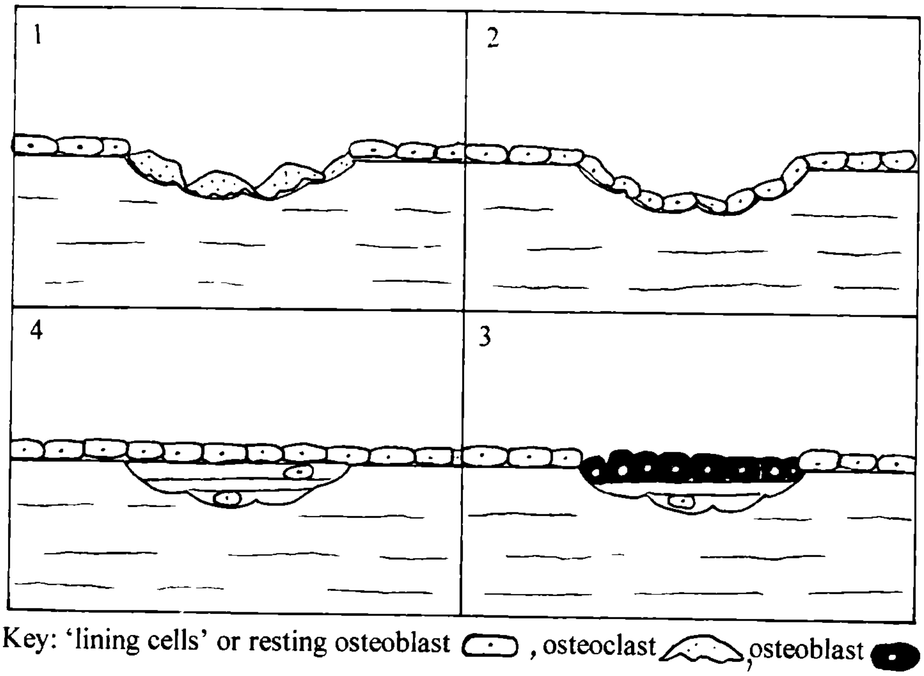


Figure 2.3.2 Schematic representation of the main features of bone turnover. 1) shows resorption of the bone by osteoclasts. 2) after the phase of resorption is complete, the resorbed area is covered by 'bone lining cells'. 3) shows a reversal of the turnover process, Osteoblasts are creating new bone at the site of resorption. Some cells are incorporated within the new bone (osteocytes). 4) shows the bone returned to a non-active phase with the surface covered by 'lining cells'. The term remodelling applies when new bone forms a replica of bone removed, in bone modelling new bone may be structurally slightly different.

2.3.3 Disruption of Bone Remodelling

The imbalance in the remodelling processes which occurs with advancing age and as a consequence of certain medical conditions (Section 3.3.7.1) may lead to the clinical condition of osteoporosis. There is still considerable debate as to the exact role each cell type plays in producing an imbalance in the bone remodelling process. Successive and overlapping phases of bone loss may be associated with differences in abnormality of the bone remodelling process. In both males and females the first phase seen is a long-term gradual loss of bone. With increased age, the osteoblast teams become less and less capable of refilling the resorption cavities created by the osteoclasts so that the thickness of the trabecular packets and consequently the trabeculae themselves decline (Dempster and Lindsay 1993). In females a brief phase of rapid loss is seen after the menopause (Riggs and Melton 1986), and this appears to be caused by a rapid turnover rate of bone with increased osteoclastic activity (Eriksen *et al.* 1985, Heaney *et al.* 1978). Reasons for accelerated loss of bone after the menopause are discussed in Section 3.3.2.

Many factors have been linked to the development of this imbalance in bone formation and resorption, but ageing is probably one of the most important (Section 3.0). With advancing age individuals bone tissue density may increase as "packets of bone escape renewal" (Boyde *et al.* 1993). With conditions such as osteomalacia bone matrix formed during the disease remains uncalcified (Ortner and Putschar 1985). Not only does bone mass decrease in old age, there are also extra skeletal physiological changes in an individual which may exaggerate the increase in fracture risk (Dempster and Lindsay 1993).

The pattern of bone loss observed in trabecular and cortical bone is different. Imbalance between bone formation and resorption results in the thinning of the cortex, from its inner (endosteal) surface, through its replacement by trabecular bone (trabecularization). Such bone is, of course eventually impossible to tell apart from the original area of trabecular bone. Porosity of the cortex also increases (Dempster and Lindsay 1993). These changes in the bone structure lead to a reduction in the apparent density.

Jayasinghe (1991) studied changes in the structure of trabecular bone with ageing and osteoporosis, and described the normal trabecular architecture expected within the lumbar vertebral bodies. Broad patterns of age change were identified within the sample studied. In bone samples from individuals with osteoporosis he noted that there had been a loss of trabecular structures. A depletion of the number of vertical plates was observed, together with a thickening of the remaining vertical trabeculae, an increase in the length of horizontal trabeculae and the formation of microcallus fractures. A thinning of horizontal trabeculae was also noticed, with some trabeculae ending in 'thin air,' being no longer connected to others. This loss of connectivity leads to deterioration of the bone structure in the way depicted in Figure 2.3.3. All these processes will predispose an individual to bone fracture.

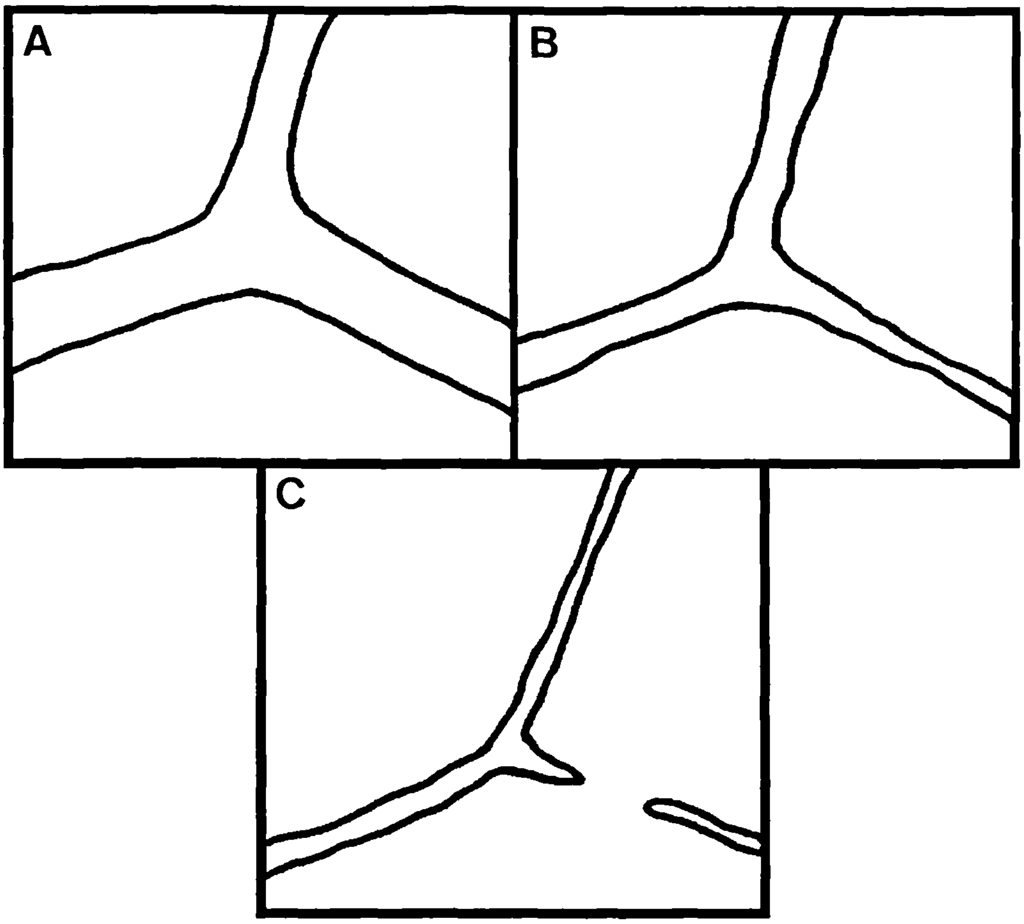


Figure 2.3.3 Schematic representation of the loss of connectivity in trabecular bone.

Bone turnover is believed to be more rapid within trabecular bone rendering it more sensitive to net loss if the remodelling processes are no longer balanced. It may be that the micro-architecture of trabecular bone is finely balanced and small bone losses can have important consequences for the structural integrity of the bone. Regions of the skeleton with a high proportion of trabecular bone, such as the vertebral bodies, proximal femur and distal radius, are more susceptible to osteoporosis-related fracture.

As might be expected with the variety seen in normal adult size and build, there is a large and continuous range in the amount of bone present in individuals (Melton *et al.* 1992). This means that it is impossible to give a specific figure for the density expected in any one adult and from this to calculate exactly when bone begins to be lost. However, as calculation of bone mineral density or content are frequently used clinically an attempt has been made to standardise the use of such data in the diagnosis of osteopenia and osteoporosis. The World Health Organisation defined osteoporosis in terms of bone mineral density or content (1994) and this was endorsed by the Advisory Group on Osteoporosis (Barlow 1994). Individuals who have values reduced by one standard deviation (SD) of the young adult reference mean have "low bone mass (osteopenia)", and those below 2.5 SD have "osteoporosis". There is, however, a wide range of figures for bone mass at which osteoporotic fractures occur (Ross *et al.* 1990).

The importance of trabecular bone in the occurrence of osteoporosis-related fractures is indicated by studies which have examined the relationship between fracture and bone mass. The ash weight of bone per cm^{-3} below which an individual could be considered osteoporotic has been calculated (Arnold 1973). However, not all individuals who fell below this level had sustained a fracture. Several research projects have indicated that the link between osteoporotic fracture and density is weak (Chappard *et al.* 1988, Cummings 1987, Ross *et al.* 1990, Pødenphant *et al.* 1987). It is possible for an individual to be judged at risk from fracture on the basis of bone mass measurements, yet the architectural arrangement of trabecular bone may still be normal, making a fracture most unlikely. On the other hand, bone mass measurement might indicate that the bone was normal yet the trabecular architecture be seriously disrupted to the point where fracture occurs (Jayasinghe 1991). Loss of compressive strength is not directly proportional to loss of mineral and it is greatly dependent on the micro-architecture of bone (Mosekilde and Mosekilde 1986, Snyder *et al.* 1993). Even slight losses can have a large impact on the likelihood of a fracture occurring. Heaney (1989), looking at fracture and mass, concluded that fatigue damage and trabecular connectivity were important factors for the occurrence of fracture. These results reflect those obtained in a study by Kleerekoper *et al.* (1987) in which broad architectural changes with age were noticed in trabecular bone. The conclusion that trabecular structure has an important role to play in determining the probability of a fracture occurring is inescapable (Beck *et al.* 1993, Jensen *et al.* 1990, Mosekilde *et al.* 1987).

2.4 Diagnostic Techniques

Investigations into the condition of bone in modern populations, and its changes with age and hormonal status, commonly utilise non-invasive *in vivo* clinical diagnostic techniques which produce results related to whole bone density. These indirect techniques aim to estimate the quantity of bone present, measuring bone mineral density (BMD) rather than the quality of bone or bone structure. Such diagnostic techniques are often used clinically to assess the likelihood of an individuals sustaining a fracture. The Department of Health report of the Advisory Group on Osteoporosis (Barlow 1994) does not recommend population screening, but states that such techniques are essential for clinical decision making.

2.4.1 Conventional X-ray

Routine X-ray procedure has the advantage that it is quick, simple and inexpensive. However, simple visual observation of conventional radiographs is inadequate as a method of diagnosing osteoporosis. It has been calculated that a patient would have to lose as much as 30% of their bone mass before osteopenia was apparent (Adran 1951, Finsen and Anda 1988). There are also problems linked to the exposure and the processing of X-ray film, for example weakening of developer solutions (Woolf and St John Dixon 1988).

2.4.2 Optical Densitometry (Radiogrammetry)

With this technique, the amount of cortical bone present in an individual is estimated by taking measurements from conventional radiographs. Several regions of the body have been used for such assessments, though the skeletal region most often chosen for study are the metacarpals. The technique was being applied clinically up to thirty years ago, but today it is little used because several disadvantages associated with its use are now recognised. Trabecular bone changes are not taken into consideration in the measurements made. In clinical use there are problems such as the movement of the patient during exposure of film. Care must be taken over the angle that the measurement is made at, as there is also possible error associated with the fact that the endosteal (inner) surface may not be clearly defined on an X-ray picture. Analysis of radiographs may be made difficult by possible variation in the hand film distance. Finally, it is not known exactly how well changes in bone through ageing seen in the metacarpals (which are not prone to osteoporotic fracture) correlate with changes at the sites within the body most prone to fracture (Virtama and Helela 1969).

Simple measurements have also been made on radiographs of the spine, in order to estimate the ratio between the heights of the intervertebral discs and the vertebral bodies (Woolf and St John Dixon 1988). There are, however, many difficulties involved with spinal X-rays. Images may be obscured by the dense bony spinous processes, or soft tissues. Furthermore it has been observed that deformation of the shape of vertebrae is relatively common, and independent of changes in bone mass (Woolf and St.John Dixon 1988). Techniques are being developed to assess trabecular structure from radiographs: atomic recognition of radiographic trabecular pattern (Geraets *et al.* 1990), analysis of bone X-rays using morphological fractals (Samarabandu *et al.* 1993), fractal signature analysis of macroradiographs (Buckland-Wright *et al.* 1993), and radiographic texture analysis (Southard and Southard 1996). Much of this work is still experimental. There are older techniques such as the Singh Index (Singh 1970) in which trabecular structure is visually assessed from radiographs of the femoral neck. A score is awarded on the basis of visibility of trabecular groups, with six being normal and one osteoporotic.

2.4.3 Photodensitometry

Photodensitometric techniques are also based on an analysis of radiographs and so the problems previously mentioned also apply. Unlike radiogrammetry these methods seek to calculate bone density from radiographs, so that trabecular as well as cortical bone is included in the measurement. Clinically an object of known density, or more frequently a scaled marker such as a step wedge made of aluminium, is placed on the X-ray film next to the area to be radiographed. The steps of the wedge allow a range of known optical densities to be obtained. The wrist and hand are the most commonly used sites (Bland *et al.* 1989, Kruse and Kuhlencordt 1983). Densities can be read from the film using an optical densitometer. The film is placed between a light source and a photoelectric cell, the output of which has been calibrated. A calibration curve may be constructed using these standards, allowing a density figure to be given to any part of the picture on film. In clinical studies a water bath may be used to eliminate soft tissue differences around bone (Barnett and Nordin 1960).

2.4.4 Photon Absorptiometry

Single photon absorptiometry was first used over twenty years ago. A collimated beam of low energy photons is passed through the site under study to a detector. Data gathered from the detector allows the attenuation of the object to be calculated, and this loss of intensity in the beam is dependent upon the mineral content of the object being scanned. Known measurement variables, such as area scanned and thickness of the object, allow the calculation of the bone mineral density in g/cm^2 to be achieved. Its accuracy error has been estimated at 5% (Delmas 1993). These figures are compared to data gathered in population studies to calculate whether or not an individual is at risk of sustaining a fracture due to osteoporosis. This method can only be used on appendicular sites such as the wrist.

2.4.4.1 Dual Photon Absorptiometry

This technique is a development of photon absorptiometry, in which two photon sources, usually gamma photons of 44 Kv and 100 Kv, are used simultaneously. It is possible by this method to measure sites which have greater amounts of soft tissue surrounding them, for example the femoral neck and spine. There is no need to use a water bath, as both bone and soft tissue can be measured at once. As in single photon absorptiometry, a figure for the bone mineral content, usually in grams per area, is produced. One disadvantage of dual photon absorptiometry in a clinical setting is that it requires a very long scanning time. Accuracy error has been calculated at 4% for dual photon absorptiometry.

Photon absorptiometry has a number of fundamental limitations. All mineral in the path of the beam is measured so that cortical and trabecular bone cannot be studied in isolation. Any other dense material such as ligamentous or aortic calcification, or osteophytes, will also be included in the measurement data, and this may lead to inaccuracies in density calculations (Woolf and St John Dixon 1988).

2.4.4.2 Dual Energy X-ray Absorptiometry (DEXA)

This development followed on from dual photon absorptiometry. DEXA has a much quicker scanning time, with a stable X-ray tube being used instead of two isotope sources. Tighter collimation of the beam provides higher spatial resolution, giving better quality images. Results are given as bone mineral density in g/cm^2. The procedure used enables a low radiation dose to the patient. However, the other problems that affected dual photon absorptiometry also affect DEXA.

2.4.4.3 Computed Tomography (CT)

Computed tomography is in routine use as an investigative tool for clinical diagnostic use and can be adapted to quantify the attenuation value of bone in terms of bone density (Richardson *et al.* 1985). It allows the three dimensional location of the measurement site to be obtained, with scans providing the equivalent of an anatomical slice or cross section. In sites such as the vertebrae, the cortical shell can be distinguished from trabecular bone, and so be eliminated from measurements. The technique is currently being developed to allow higher resolution scans. It is now appreciated that it is useful to develop the technique to allow whole bone measurement or isolation of the trabecular region (Cann 1988, Jones *et al.* 1987). However, there are problems with the technique. The dose of radiation received during a scan is large, causing problems in a clinical setting if scans are to be repeated. Another drawback is that the equipment is extremely expensive. There are also unanswered questions about the precision error of the technique. Both these latter factors have a bearing on the possible use of such equipment on archaeological bone. Clinically when used to measure the density of a volume within the trabecular region, a considerable amount of fatty and red marrow is included and, at present, the technique is not free from artefact. For example, although the cortex of a vertebral body is no thicker than many trabeculae, it always appears as a thicker line in the images.

2.4.5 Histomorphometry

As mentioned previously, fractures occur through a deficiency in the quantity and structural arrangement of trabecular bone, rendering a bone less resistant to forces placed upon it. It is for this reason that biological researchers studying bone loss and osteoporosis have chosen to look at trabecular bone patterns through the study of autopsy and biopsy material. Biopsies have been widely used since the introduction of the technique in the late 1960's (Boyce 1989). Cores of bone are removed for analysis from the iliac crest region, which contains trabecular bone and is accessible in living patients. Autopsy samples can be taken from any skeletal region, but the availability of both biopsy and autopsy material is limited. Biopsy is only commonly available from the iliac crest; samples cannot be taken from areas liable to fracture, such as the vertebral bodies or femoral neck. With autopsy material, younger individuals are rarely available and there are numerous restrictions on obtaining samples.

Changes in bone with age in autopsy and biopsy material is often studied through classical histomorphometry in which stereological calculations are applied to a set of two dimensional measures to calculate changes in volume and surface area fractions in samples (Faccini *et al.* 1976, Grote *et al.* 1995). Such data are obtained from sections of bone which have a certain thickness and are therefore invalid as a starting point for stereology since this requires the assumption of an infinitely thin section (Boyde *pers. com.*). More importantly, these methods fail to contribute to our understanding of the complex three dimensional aspects of connectivity, shape and spatial distribution of trabecular bone. Hahn *et al.* (1989) developed a method which allowed the two dimensional cut surface of bone to be observed in conjunction with the trabeculae beneath, and demonstrated that the surface structure did not always accurately represent the underlying three dimensional structure. Thin sections of trabecular bone are therefore not regarded as a reliable predictor of three dimensional architecture (Jayasinghe 1991). The quantification of a complex 3-D structure such as trabecular bone is difficult or even impossible by 2-D methods.

The techniques listed above are some of the more common ones being used clinically to detect bone loss and osteoporosis, but there are also many others being developed to improve screening. The huge range of research being carried out within this field is a measure of the size of the problem, and considerable sums of money have been made available for studies of diagnostic methods including: radioisotopic scanning (Alazraki 1981), ultrasonography (Agren *et al.* 1991, Gluer *et al.* 1992), neutron activation analysis (Anderson *et al.* 1964 and Reid 1986), low angle X-ray scattering (Royle and Speller 1991) and Compton scattering (Hazon *et al.* 1977).

2.5 Osteoporotic Fractures

The major areas for osteoporosis-related fracture are the proximal femur, the distal radius, and the vertebral bodies. Other sites of fractures resulting from osteoporosis, such as the innominate, humerus and distal tibia, arise less frequently. A characteristic of many osteoporotic fractures is that they are produced by low trauma events, for example jumping off a step.

2.5.1 Femoral Fractures

Fractures of the hip (intra-capsular fractures of the proximal femur) are probably the most serious fractures caused by osteoporosis (Royal College of Physicians, 1989). In 1994 it was estimated that there were sixty thousand hip fractures in Britain each year (Barlow 1994). Such a fracture can have devastating consequences for the individual. On fracture, from two to three pints of blood can be lost into the top of the leg, and such an injury will be a massive shock to the system of older individuals (Kanis 1994). Figures vary but it has been estimated that 12-40% of patients die within six months of a fracture (Miller 1978, Cummings *et al.* 1985, Lewinnek *et al.* 1980). Spector (1991) estimated that a quarter of individuals who sustain hip fractures die within the next year, and half will be unable to walk unaided. Such a fracture leads to loss of independence through reduced mobility. These figures for morbidity and mortality are extremely high considering that they are for individuals with access to modern health care. Mortality in past populations from such fractures would undoubtedly have been much higher.

2.5.2 Vertebral Fractures

Vertebral fractures are normally far less traumatic than femoral fractures, but more frequent. Loss of bone from the vertebral body makes it more susceptible to becoming crushed or wedged. Such compression fractures can be caused by very minor trauma and, in an individual who has lost a considerable amount of bone, even coughing may be enough to cause them. In a study by Kelly and co-workers (1990), it was estimated that 83% of vertebral fractures occurred as a result of moderate or no trauma. They can also be brought about by putting a load on outstretched arms, for example when raising a window (Lukert 1994). Up to 50 % of fractures of this type are asymptomatic (Peel and Eastell 1995). There may be some back pain, but this normally ceases within several weeks although, in some cases, pain may be more severe and remain intense for 2-3 months. Occasionally there may be complications such as urinary retention and, in extremely rare cases, neural cord compression. Clinical signs of this type of fracture include loss of stature with associated abdominal protuberance, and unnatural curvature of the spine (kyphosis). Such distortions of the spinal column may cause abdominal compression and reduced respiratory function. The nature of vertebral compression fractures makes it extremely difficult to calculate accurately the numbers of people affected, but some estimates put the incidence three times greater than hip fractures (Spector 1991). They commonly occur in women up to the age of seventy, and it has been estimated that over a third of European women will sustain such a fracture by this age (Kleerekoper and Avioli 1990).

2.5.3 Colles' Fracture

Fractures to the distal radius, known as Colles' fractures, are today the most common fracture in Caucasian women below the age of seventy (Stevenson 1991). They are usually relatively simple to treat and do not normally result in admission to an in-patient ward of hospital, as they do not carry a high rate of mortality. The majority of such fractures are treatable in an out-patient department, with limited follow-up treatment at a fracture clinic. Most Colles' fractures are sustained when a falling individual puts out a hand for protection. Not all such fractures are related directly to osteoporosis, although a large number of those in the elderly, particularly in women, are likely to be linked to the condition.

2.6 Prevention and Treatment of Fractures

The treatment of osteoporosis-related fractures falls into two broad categories. There are preventative treatments which aim to prevent fractures happening, and the treatment of fractures which have already occurred.

2.6.1 Preventative Treatment

Because of the ever increasing costs associated with osteoporosis, an Advisory Group on Osteoporosis was set up by the Department of Health. In 1994, the advisory group published a report (Barlow 1994) outlining procedures for combating the condition and preventing fractures from occurring. Osteoporosis is now considered to be a preventable condition, which can be controlled with the use of various drugs or food supplements. It is hoped that such treatments will prevent further bone loss and may even promote an increase in bone mass, protecting a patient who has already sustained a fracture from further fractures, and, if taken from the time of the menopause, eliminate the risk of osteoporotic fracture. Several drug treatments aimed at improving bone mass are available, the best known being hormone replacement therapy.

A different approach to protecting patients who may be at risk from sustaining osteoporosis-related fractures is to improve their agility, and so reduce their liability to fall, by physiotherapy to counteract muscular weakness and improve balance and reflexes (Barlow 1994). Weight bearing exercises are also to be encouraged, and appropriate walking aids to be supplied to those with severely impaired mobility. Hazards such as loose mats and cables should be removed from the home, and care is taken to correct visual impairment. Another suggestion is the use of hip protectors, designed to absorb the impact of a fall onto the hip (Peel and Eastell 1995). Care needs to be taken that drugs prescribed do not cause drowsiness and place an individual at greater risk (Stevenson 1991).

2.6.2 Post-Fracture Treatment - Surgery

All fracture treatments today aim to allow early restoration of function and weight bearing. It is generally agreed that good nutrition is important to speed recovery and healing of the injury, and that the patient receives sufficient calcium and vitamins (Barlow 1994, Peck 1984, Woolf and St John Dixon 1988). In the elderly, regeneration of injured bone may be prolonged, so that hospitalisation or home bed rest may lead to a long period without weight bearing on the limbs. This may cause further acceleration of bone loss making healing difficult (Sneed and Van Bree 1990). Finding ways in which the healing process may be improved or speeded up is vital, because unless patients are helped back to mobility quickly they may become permanently institutionalised. Such an outcome would mean that considerable resources would need to be spent and the quality of the patients lives would decrease.

Following femoral neck fracture there is a 20% risk of avascular necrosis of the femoral head due to the loss of blood supply, because the vessels tear at the time of injury (Barlow 1994). Because of this risk, most patients over the age of 75 are managed by primary prosthetic replacement of the femoral head in preference to reduction pinning. Intertrochanteric fractures do not develop this complication, but are often more technically difficult to reduce and fix, with a high 15-20% incidence of non-union. When vertebral crush fractures occur they are usually not treated beyond pain relief, but occasionally paraplegia can result (Shikata *et al.* 1990).

2.7 Discussion

Definitions of osteoporosis such as that quoted (Section 2.2) in which the amount and architectural arrangement of bone tissue are mentioned make clinical diagnosis difficult. Often individuals are not diagnosed as osteoporotic until a fracture occurs. Currently bone mass levels are the main clinical criteria by which an individual is judged to be osteoporotic, but the over riding limitation of the non-invasive investigative techniques described above is that density is not the absolute indicator of an individual's liability to sustain a fracture (Mosekilde and Mosekilde 1986). None of the above methods is capable of determining the bone structure, which appears to play a more important role in the likelihood of osteoporosis-related fracture (Section 2.3.3).

None of the treatments described would have been available to the 18th and 19th century people considered in the present study. The aetiology of fractures in the elderly was not properly understood, and preventive measures such as physiotherapy and home improvements would not have been available. Drugs which aim to prevent bone loss have only recently become available. Without anaesthetic or antiseptic surgery the internal fixation of fractures was definitely not an option and none of the other treatments routinely given today would have been available, for example, blood transfusion following a hip fracture. Treatment of individuals who suffered fractures would have been limited to splinting and bedrest (Section 4.7). As a result morbidity and mortality associated with osteoporotic fractures would have been high during the period covered by the present study.

3. Current Research into Osteoporosis

3.1 Introduction

When undertaking a study of a condition in the past, it is important to start with a full understanding of all aspects of the condition in present day populations. A knowledge of the factors which may contribute to the onset and severity of osteoporosis is vital. Such information will enable an informed judgement to be reached about how changes in lifestyle factors through time may influence a condition. Some factors which are today considered to play a role in the onset and development of osteoporosis may also have been present in the past. Others such as drug treatments which have only become available comparatively recently can be ruled out.

3.2 Epidemiology

Osteoporosis is now recognised as a world-wide health problem. "In the UK there are approximately 60,000 hip, 50,000 wrist, and 40,000 clinically diagnosed vertebral fractures annually due to osteoporosis" (Barlow 1994). As has been mentioned (Section 2), there are sex-related differences in rates of osteoporotic fracture. Women are far more susceptible to this type of fracture than men. The lifetime risk calculated for a fifty year old woman to suffer a vertebral fracture is 32%, whereas women of the same age have been calculated as having a 31% chance of dying from a heart attack (Stevenson 1991). Part of the reason for this may be that on average women do not attain such high peak bone mineral density (BMD) as men, and on average live longer.

The epidemiology of osteoporosis presents several problems to those engaged in its study. The most notable difficulty is that the development of the condition itself is unnoticed by the person affected, and it is not until a fracture occurs that an individual is likely to be recorded as osteoporotic. Attempts have been made to use data from hospitals on the incidence of fracture to postulate levels of osteoporosis within populations. With hospital records there are several problems; for example patients with hip fracture may be admitted to one department and then transferred to another, or even be moved to another hospital (Fenton-Lewis 1981). These entries for admissions could easily be misinterpreted. Most data relating to osteoporosis are gathered from records of treatment, and therefore only provides data on those individuals who received treatment. It is very difficult to obtain true morbidity data that will permit a valid comparison over time.

There is also some debate about whether levels of osteoporosis should be calculated from data relating to bone loss, or actual fracture (Chalmers and Ho 1970, Melton *et al.* 1992). An alternative is to select representative groups from the population and use non-invasive techniques to measure any decline in bone mineral density through time. Such an approach assumes that the condition is dependent solely upon density, as structure cannot be analysed in this way. The problem with all epidemiological studies lies in the fact that "there is no single necessary and exclusive attribute of osteoporosis by which it can be counted, no hallmark that says osteoporosis is or is not present" (Woolf and St John Dixon 1988, p.26).

3.3 Factors which May Contribute to the Onset of Osteoporosis

Growing public awareness of the condition, initiated by the financial cost to the country caused by morbidity, has led to a large amount of research into the condition over recent years. Many different factors which may play a role in the onset and development of the condition have been identified. There is a huge amount of literature in scientific journals, some devoted entirely to osteoporosis, covering all aspects of the condition. In this Section the main factors considered to play a role in the onset of the condition and its development are summarised.

3.3.1 Heredity

A genetic link to peak bone mass and integrity of trabecular structure is suggested by the fact that some families appear to have a history of osteoporotic fracture. The peak bone density and structural integrity achieved by an individual as a young adult has obvious implications for an individual's susceptibility to developing osteoporosis. The relationship between structural integrity and genetics has not been examined, but peak bone density appears to be strongly influenced by genetic factors (Chestnut 1991). Another indicator that genetic factors have a role is that black women have been shown to attain a higher peak bone density and as a result are far less susceptible to osteoporosis (Bell NH, *et al.* 1991). A study carried out by Burns (1992), in which the role of genetic factors was analysed, concluded that they may account for around 50% of differences observed in peak femoral bone density. The role of genetics in obtaining peak bone density has been set as high as 70% by some researchers (Peel and Eastell 1995). Quite how genetic factors are linked to bone density is not known. In a few patients with osteoporosis altered collagen have been identified (Prockop 1992) which may be contributory factors.

A problem faced by all studies into the role of heredity in any condition is the difficulty in separating hereditary and environmental factors. The best approach to overcome this problem is to study twins. It should be remembered that even in utero, environmental factors are active, for example inequality of placental nutrition (Woolf and St John Dixon, 1988). Such studies are also inevitably limited by the sample size available. Monozygotic twins appear to show greater similarity of bone density than dizygotic twins (Smith *et al.* 1973), but as these individuals age, differences become greater. It would thus appear that bone density is initially genetically determined, but this is not totally dominant. Divergence with age may be linked to behaviour and environmental factors encountered.

3.3.2 Hormones

Hormones play an important role in the regulation of all processes within the body including bone formation, development and turnover. There are a number of hormones present in the body which are calcium regulating, and therefore have an important effect on bone. Parathyroid hormone (PTH), which influences bone cell activity, is the most significant regulator of extracellular concentrations of calcium (Woolf and St. John Dixon 1988). Long standing hyperthyroidism can lead to an increase in the rate of bone remodelling, and may be linked to direct action of the thyroid hormone on rate of bone turnover (Kanis 1994, p.89).

The sex hormones in particular seem to have a significant role to play in the regulation of bone turnover. Oestrogens, which are related to ovarian function, appear to be very important in maintaining bone. Loss of ovarian function can be brought about by the menopause, or surgical ovarectomy, causing a sharp decline in levels of oestrogens. Bone loss in women after the menopause is particularly rapid and appears to be directly related to oestrogen levels. It is thought that a fall in oestrogen levels may cause osteoclasts to become hyperactive, resorbing large areas of the trabecular plates, perforating and weakening them (Dempster and Lindsay 1993). Research into the effect of oestrogens has not yet established the exact sequence of events involved in the loss of bone. It is still unclear whether losses are caused by an increase in the activity of individual osteoclasts, or if there is an increase in the recruitment of osteoclasts to a specific area of bone. There may be a combination of these two activities. With loss of oestrogen there is increased remodelling of bone both at sites of formation and resorption, and with each remodelling cycle there is a small net loss of bone, leading to high overall bone loss (MacDonald and Gowen 1993). Other systemic hormones such as glucocorticosteroids, insulin, growth hormone, somatomedins and, thyroid hormone, and prostaglandins and, cytokines also influence bone turnover.

It is now widely accepted that in young women, extreme levels of exercise can have a negative effect on bone, even leading to fracture. Complex hormonal disturbance may result from high levels of physical training leading to amenorrhea (Carbon 1992). Such hormonal disturbance can lead to lower bone mineral density and possible osteoporosis-related fracture (Fogelman 1996, Reid 1997).

3.3.3 Pregnancy

Research into the possible links between pregnancy and osteoporosis has not been extensive, and clinical descriptions of cases in which there appears to be a link are few. It is often unclear if, in the cases that have been reported, the relationship is accidental or causal. Pregnant women do not often become osteoporotic, so the condition is not routinely checked for. When it does occur it appears that the area most commonly affected in such cases is the spine, though transient osteoporosis leading to hip fracture has been reported. However, the condition was not seen to worsen, or recur, in future pregnancies (Smith *et al.* 1985). Investigations into a possible relationship have been hampered by the fact that women are often not referred for treatment until after a fracture has taken place.

3.3.3.1 Lactation

Two recent studies attempted to assess the impact of breast feeding on bone density using dual-photon absorptiometry (Melton *et al.* 1993, Stevenson *et al.* 1989). The number of children an individual had, how many were breastfed, and the length of time of any breast feeding were considered in the study by Melton and colleagues. These factors were not found to be associated with a reduction in bone mineral density. A possible link was observed between a higher bone mineral at some sites and breast feeding for a period of 8 months or longer. However, when figures were adjusted for the age of the mother, age at first delivery, age of gravidity or parity, age at menarche, use of oral contraceptives, oestrogen replacement therapy, various sex hormones or any other reproductive factor considered, no consistent effects on bone mineral could be observed. Both studies produced similar results. These findings are the same as those obtained by Stevenson and his co-workers (1989). An additional observation was, however, made in the study by Melton (1993) and colleagues, who found a slight negative effect of nulliparity in the vertebrae. Although studies on animals have indicated that pregnancy and lactation may cause calcium to be lost from the skeleton, these factors appear to have little long-term effect in most women (Melton *et al.* 1993).

3.3.4 Exercise

Exercise has an undoubted influence on bone formation and development, and consequently it has been widely studied. Researchers have looked to see if various types of exercise may have different effects, and what time periods are needed to bring about change. An inherent problem in any such work is that any results obtained from the study of exercise may be influenced by other lifestyle features in the subject's life, both past and present. Such factors could include the age of the individual, and past levels of exercise. This inevitably leads to difficulties in interpretation of data, and there will be problems over how much reliance can be placed on the results.

Many studies have concluded that there is a connection between bone density and exercise (for example, Dargent and Breart 1993, Lohman 1992). In a review by Kanis (1994) it was found women who sustain an osteoporotic fracture often have a lower muscle density than age-matched controls. It may be that there is no actual increase in bone mineral density (BMD) with exercise, and that what is actually being observed is a decrease in fat and an increase in the lean muscle. Such soft tissue changes could affect the accuracy of the measurements. Rogers and Evans (1993) found age-related loss in total body nitrogen is closely related to the losses in total body calcium, suggesting that reduced bone density seen in the elderly may be associated with the loss of skeletal muscle. A sex difference in the rate of change in body composition over time has been seen (Rogers and Evans 1993). Older individuals adapt to resistive and endurance exercise training in a similar fashion to young people, and the decline in the muscle's metabolic and force-producing capacity can no longer be considered an inevitable consequence of the ageing process (*ibid.)*. However, not all studies agree. In a study involving 216 British women it was observed that, for a given age, levels of physical activity did not correlate with figures for muscle or bone density (Rutherford and Jones 1992). In short, these studies indicate that losses of bone and muscle with age do not have a simple link to activity.

In experimental and clinical studies carried out by Inoue *et al.* (1993), it was found that the level of exercise required to produce a favourable effect on tissues was highly variable between the sexes, and even between individuals of the same sex. Reasonable levels of exercise were observed to have an effect on all bone provided there was enough calcium in the diet. It was concluded that exercise may help prevent bone loss. It is not, however, clear how beneficial exercise is above normal levels (Stevenson *et al.* 1989), and the benefits obtained from exercising probably vary with age. In pre-menopausal women regular exercise was not seen to have an influence on bone density, but in post-menopausal women there was a significant difference ($p<0.05$) in the proximal femur density observed between women who did, and did not, exercise regularly. Body weight and the period which had elapsed since the menopause were considered as covariates (Stevenson *et al.* 1989).

The role that exercise plays at a younger age is far from clear. In an attempt to clarify the situation Slemenda and co-workers (1991) undertook a study of 118 children aged 5-14 years. Significant positive relationships were seen between most physical activities undertaken by the children and the BMD of hip, spine and radius. Overall the results obtained showed that the amount of time spent engaged in physical activity was related to the BMD of the radius and hip. This relationship was independent of the sex and age of the children. The results indicate that higher BMD may be linked to physical activity during childhood (Dargent and Breart 1993). However, there is a possibility that it was only those individuals who were healthier, with better physique, who were undertaking larger amounts of exercise, and the numbers in this study were limited. Investigations into the effects of exercise upon younger children have been hindered by difficulties in developing techniques which can measure accurately the amount and distribution of muscle, fat and bone in them. Existing methods of detecting body composition may not be sufficiently accurate to detect small changes occurring over a short period of time. It is also claimed by Lohman (1992) that the studies which have been carried out have not been well designed. There have been problems in obtaining large enough sample groups, and the exercise training carried out has not been over a sufficient period to allow any clear results to emerge. It is suggested by Lohman that larger studies over a longer time period with the use of techniques such as dual X-ray absorptiometry (DEXA) should be undertaken.

Immobilisation of an individual may also lead to the development of osteoporosis (Mazess and Wheldon 1983). Prolonged periods of bed rest, for example, can bring about rapid rates of bone loss, leading to several characteristic radiographic features in just a few weeks (Kanis 1994). Bone loss of this nature can occur in an individual of any age.

Despite the many problems involved in the various studies undertaken, almost all point to a link between lack of exercise and osteoporotic fractures in the elderly. The exact levels and type of exercise that would be beneficial are still, however, being debated.

3.3.5 Nutrition

Much research has been carried out to try to ascertain the possible effects of various dietary components upon the formation and remodelling of bone. Any dietary element affecting these processes may have implications for the development of osteoporosis. Calcium, being a major component of bone, has been much studied (Sowers 1993). It is vital that adequate calcium is obtained during the period of growth and development for an individual to achieve their genetically programmed peak skeletal density (Matkovic *et al.* 1990). In the older individual, calcium also has an important role to play in maintaining bone density. During the first few years after the menopause, calcium needs are met partly by the breakdown of the skeleton (Recker 1993 p.163), and this contribution declines with time.

A low intake of calcium has been put forward as one of the important risk factors in osteoporosis. On the basis of studies in the former Yugoslavia, it has been suggested that calcium may be an important determinant of bone density in young adults (Orimo *et al.* 1992), but these findings were questioned by Stevenson and Whitehead (1982) who concluded that there was no good evidence that oral calcium supplements can prevent senile osteoporosis. They commented that levels of osteoporosis are in fact higher in societies with a high average level of calcium consumption than those where it is low. Estimations of total body calcium using neutron activation analysis have indicated that large oral calcium supplements do not prevent further bone loss in women with postmenopausal osteoporosis (Stevenson and Whitehead 1983).

Perhaps the most widely cited evidence for an important role for calcium comes from studies in the former Yugoslavia (Matkovic *et al.* 1979), which have suggested that the amount of cortical bone present in women was greater in a community taking a high-calcium diet than in one with low calcium intake. The question arises as to whether this association is caused by, or related to, other differences between the two communities. An analysis of the data (Kanis 1991) suggests that there were significant differences in energy expenditure between the two communities. It is likely that the community with the high calcium intake expended considerably greater energy in physical activity, compared to the low calcium community (Kanis and Pitt 1992). Thus it is possible that the level of exercise, and not calcium intake, was a major factor in determining bone density.

In certain conditions, for example pernicious anaemia, calcium levels may become an important factor, as the gastric acids which are necessary for the absorption of dietary calcium are absent (Eastell *et al.* 1992). As with studies of other conditions which may lead to the onset of osteoporosis, it is very difficult to separate one factor from others which may be affecting bone remodelling.

Vitamin D intake is frequently studied in relation to osteoporosis. Deficiency can lead to defective bone formation and cause calcium malabsorption (Lamberg-Allardt 1991), and seems most harmful in older individuals who may have reduced exposure to sunlight. Although there is little firm evidence for the link, it is plausible (Kanis 1994). A diet with low protein levels and prolonged vitamin D deficiency during childhood has been observed to have a significant effect on skeletal development and bone density attained (*Ibid.* 1994), but their impact on fracture risk in later life is not known. Proteins and phosphates have also been put forward as playing a role in the onset of osteoporosis, but this situation is far from clear, because a protein-rich diet will lead to the formation of acid urine which can in turn cause urinary calcium loss.

Many other vitamins and food components have been considered in relation to osteoporosis, for example phosphates, which are used as food additives (Woolf and St John Dixon 1988). Sodium intake may also have a contributory role. It has been shown in experimental animals that individuals with diets high in sodium have a raised excretion of calcium (Goulding 1981), and high sodium levels in the human diet may be linked to greater bone turnover, as measured by the urinary excretion of hydroxyproline. Kanis (1994) suggested that long term intakes of large amounts of sodium might accelerate calcium losses.

In some studies, patients with osteoporosis have been noted to have high caffeine intakes, and as a result the possibilities of a link have been examined. It has also been found that urinary excretions of calcium may be increased by administering caffeine containing drinks (Heaney and Recker 1982). There is, however, no firm data linking caffeine consumption to osteoporosis and, although cohort studies have been carried out, the results are conflicting. Moreover tea, which also contains caffeine, appears to be associated with a decrease in hip fracture risk, perhaps related to the presence of oestrogenic flavinoids (Kanis 1994). In another study, the amounts of caffeine normally consumed by individuals were found to pose no risk with regard to osteoporosis (Cooper *et al.* 1992), although a high intake in elderly women, could cause some bone loss in the femur.

Alcohol intake may also be linked to osteoporosis. Alcohol consumption in humans and experimental animals has been associated with reduced rates of bone formation (Diamond *et al.* 1989). It was suggested in this study that another factor which may play a role in loss of bone in humans is the observed link between high levels of alcohol and severe disruption to the diet, for example protein undernutrition. Other associated factors such as a decrease in testosterone and liver disease may also play a role, and men in particular are at risk from such bone loss. In a study by Laitinen and co-workers (1991), small doses of alcohol were given to healthy young adults. It was observed that there was some effect on calcium metabolism, which suggested that prolonged moderate alcohol consumption may impair osteoblastic function. These findings are backed up by those of Cheung and colleagues (1995).

Body weight has also been identified as a contributory factor, individuals who are severely underweight having a high risk of osteoporosis (Stevenson 1991). It is suggested this is because very low body weight can lead to hypothalamic hypogonadism which results in oestrogen deprivation. An extreme example is anorexia nervosa. Obesity by contrast has been shown to have a protective role. Although the postmenopausal ovary no longer produces oestradiol, it secretes a small amount of androstenedione and this, together with adrenal androstenedione, is converted to oestrogen in adipose tissue. This may explain why obese menopausal women have a lower risk of osteoporosis than slim postmenopausal women. In the event of a fall, the additional adipose tissue may also act as a cushion, further reducing the likelihood of a fracture. In the review by Woolf and St John Dixon (1988), it was reported that high body weight is also associated with increased loading of the skeleton, which has a significant effect on bone density, causing it to increase.

The necessity of good overall levels of nutrition for general well being and healthy bones was shown by Rico and co-workers (1993), who found a correlation between women with osteoporosis and low levels of biochemical markers of nutrition. As can be seen from the discussion above, many nutritional factors can aggravate a condition such as osteoporosis.

3.3.6 Smoking

Smoking has been implicated as a contributory factor in the development of osteoporosis, particularly of the spine. The reason for this supposed link is not known, but a number of suggestions have been advanced (Ernst 1992). One theory is that it may be due to the generally 'unhealthy' lifestyle smokers are perceived to lead. Another is that smoking decreases appetite and as a consequence body fat. Vertebral fractures can be caused by relatively low impact stress, and more frequent coughing in smokers may increase the risk of vertebral crush fractures. Experimental evidence has so far failed to support such a hypothesis. A new theory was put forward by Ernst (1992 and 1993) who suggested that smoking causes 'malnutrition' of the discs, brought about by factors such as changes in blood flow pressure leaving them more susceptible to mechanical stress.

3.3.7 Medication

A number of drugs administered clinically for various other conditions have been observed to contribute to the onset of osteoporosis. A substantial body of literature now provides evidence that glucocorticosteroids, which are used to treat inflammation, result in osteoporosis (Gennari and Civitelli 1986, Reid and Grey 1993). The main effect of this group of drugs is inhibition of osteoblast proliferation and function. In addition, several drugs used in the treatment of hyperthyroid patients can result in reduced bone mineral density (Kanis 1994), and similar effects are noted for anticonvulsants, heparin, lithium and cytotoxic drugs.

3.3.7.1 Other Medical Conditions

There are several medical conditions which are linked to an early onset of osteoporosis. Such conditions include Cushing's syndrome, coeliac disease, leukaemia, osteogenesis imperfecta and homocystinuria. Idiopathic juvenile osteoporosis is very rare and the exact causes of the condition are not known (Smith 1980). It usually occurs before puberty and is reversible, but can result in compression fractures of the vertebrae, and fractures of the long bones. Idiopathic generalised osteoporosis can also occur in adults, particularly premenopausal women and young men, but again it is very rare and there is often a failure to identify a cause (Woolf and St John Dixon, 1988, p.84-6).

3.4 Discussion

As can be seen from the above summary of current research, the possible causes of osteoporosis and contributory factors are numerous and widely varied. Cases of secondary osteoporosis are those which can be attributed to a single cause such as alcoholism. Primary osteoporosis (Type I postmenopausal and Type II senile) are harder to attribute to a single cause. In postmenopausal osteoporosis although the primary cause is hormonal change, other lifestyle factors may contribute. In cases of senile osteoporosis it would be extremely difficult to pin down precisely which of the many factors related to osteoporosis had the biggest influence in leading to an individual sustaining a fracture. No one factor is so clearly related that it can be used to identify individuals at risk, bone loss will have many contributory factors operating over the lifetime of the individual.

Until it is clearer how much weight can be given to the many factors which might cause or worsen the condition it is not safe to draw conclusions about a past population. Facts relating to the lifestyles of past populations are incomplete making the drawing of conclusions very difficult. Details relating to the life of an individual are seldom known and there are many problems with ageing of archaeological material. Although it may be suspected that an individual had secondary osteoporosis without knowledge of specific details of the persons life this would be difficult to prove and the causative factor could not be identified.

4. Historical Evidence

4.1 Introduction

One approach to the study of osteoporosis in past populations is through documentary evidence relating to healthcare and fractures in the past. A comprehensive review of such material has never previously been undertaken. Although fragmentary in nature, the use of historical evidence will add valuable additional material which cannot be gained from the archaeological skeletal material. There is a large body of historical material relating to medicine during the period covered by this study, housed at various institutions in London. The material consulted included hospital records, death registers, early medical textbooks, case notes, private letters between doctors and pathology museum collections. The term osteoporosis has been in use for 150 years but in the past it was applied to a wide variety of conditions. The word seems first to have been used in France around 1820. Research by Schapira and Schapira (1992) led to the discovery that the term was coined by Jean Georges Chrétien Frédéric Martin Lobstein 'the younger' (1777-1835), a French pathologist. It appears that the word occurred to him in the context of osteitis (inflammation of the skeleton leading to porosis). Linguistically the term is derived from the Greek *osteon* meaning bone and *poros* meaning little hole. It literally meant 'porous bone'. Osteoporosis appears in various French and German dictionaries of the nineteenth century, but is absent from either English or American dictionaries until the beginning of the twentieth century (Schapira and Schapira 1992). These findings are backed up by the present research into London material; here the word osteoporosis appears not to have been used amongst the medical profession in London even during the later period covered (1700-1850).

The condition of osteoporosis is 'silent' in that, certainly in the historical period under study, there would be no evidence for any problem within the bone until fracture. Fractures are, however, a common feature of osteoporosis in modern clinical literature (Section 2.5), and a number of early medical works deal with the subject. The picture gained from such evidence will inevitably be less full than that available for research into the current prevalence of the condition, and data on bone loss obtained through clinical diagnostic techniques or standardised hospital records, has only recently become available. In addition an individual could have lost a considerable amount of bone and have severely disrupted bone structure, making the individual liable to sustain a fracture, but die of an unrelated ailment which today may well have been treatable. During the last century, more individuals died prematurely of unrelated conditions making osteoporotic fractures less frequent (Section 6.1).

It is impossible to be certain that the cases contained in the early medical literature are definitely related to osteoporosis, but reference to the features that characterise osteoporotic fracture (Section 2.5) will give an indication of whether this is so. The important features in determining whether or not the fracture described is due to osteoporosis include:

a) site of fracture.
b) age of the Individual.
c) sex of the individual.
d) circumstances of the fracture.
e) descriptions of bone given in autopsy notes.

Osteoporotic fractures are most frequent in bones with a high trabecular bone content, such as the neck of the femur, the distal radius and the lumbar vertebrae. Secondly osteoporotic fractures commonly occur in older individuals, with women more often affected than men (Section 3.2), so it is very unlikely that a fracture caused by osteoporosis would be sustained by a young healthy male. Where available, descriptions of internal bone structure are sometimes clear enough to allow osteoporosis to be suspected. If autopsy notes refer to the bone as having a thin cortex, with the trabecular bone being far sparser and less connected in structure than expected (often described as having a 'spongy' texture) then it is reasonable to suppose that the bone in question was osteoporotic. The details of all the circumstances of the fracture were also considered, because osteoporotic fractures are often characterised by minimal trauma. The simple act of a person stepping down from a pavement may be sufficient for an osteoporotic bone to fracture, and violent coughing may cause a vertebral crush fracture. If cases described contain a number of these criteria, there is a strong possibility that what is being described is a fracture due to osteoporosis.

The nature of texts documenting medical matters is undoubtedly influenced by the ways in which health care provision was made during the period. There were a number of hospitals in London, established by voluntary contributions from wealthy individuals, or money provided by the church, during the period covered by this study. Such institutions were intended for good and worthy poor people who could not afford to pay for hospital treatment. Evidence for this can be seen in case notes in which great emphasis was placed on the good moral character of the patient. In many cases such details appear to have been considered more important than clinical features of the case in question. The patients at St. Thomas' Hospital were even given books on morality and piety, such as *Directions and Prayer for the use of the Patients* (McInnes 1963). In a number of case notes examined, the doctor commented where an individual died in hospital that the patient was not a very upstanding citizen or had immoderate habits, as if the lack of morals was almost the cause of demise.

Those who could afford to do so would have employed the services of a doctor privately. A doctor with a good reputation would make a far better living than one without, so that in writings about their work, or in debates on medical practice of the day, many doctors were reluctant to admit any sort of failure. This can clearly be seen in the debate surrounding fractured femora. Personal rivalry is also shown in the writings of Mr. Pott criticising Mrs. Mapp, a well known bone setter of the period shown in Figure 4.1.1. He wrote of the "absurdity and impracticability of her promises," referring to her as an "ignorant, illiberal, drunken female savage" (1767, p.2). There were also many satirical cartoons produced in papers in which members of the medical profession were portrayed as charlatans and quacks. Generally, the profession had a different standing from that enjoyed in more recent times, and this undoubtedly influenced the way in which cases were recorded.

Figure 4.1.1 'The Arms of the Company of Undertakers' by William Hogarth. Mrs Mapp also known as 'Crazy Sal' is the top central figure, pointing to a bone.

4.2 Anatomy and Autopsy

Throughout most of the period under study, opportunities to carry out post-mortem investigations were severely limited. For a considerable period of time, from the sixteenth century until 1831, only bodies of criminals hanged for murder could legally be obtained by anatomists. In 1827-8 an anatomist was convicted for illegal dissection of material (Richardson 1987, p.XV). As a result of growing pressure from the medical profession the bill of 1831 was passed, and this has remained the basis of modern law on the subject until very recently. It meant that the government could confiscate the bodies of paupers who died either in a workhouse or hospital who were too poor to pay for their own funerals. Prior to this, there was growing eighteenth century interest in anatomy and physiology and this, combined with the demands of the medical profession to improve anatomical knowledge, created a black market for bodies (Richardson 1987). There was a widespread general public knowledge and fear of body snatching throughout this period, particularly amongst the poor. The poem Mary's Ghost illustrates general public awareness that such practices were being carried out.

> The arm that used to take your arm
> Is took by Dr Vyse,
> And both my legs have gone to walk,
> The hospital at Guy's.
>
> The cock it crows, I must be gone,
> My dearest we must part,
> But I'll be yours in death, altho'
> Sir Astley has my heart.

That there was considerable dissatisfaction with the law as it stood before the change in 1831 is shown by the writings of those in the medical profession such as Sir Astley Cooper, who wrote at length in journals such as *The Lancet,* campaigning for the need for greater access to bodies. He stated that, if obstacles in the way of those wishing to pursue such studies were not removed it would "put an end to the study of anatomy altogether" (1823 a, p.62). Sir Astley Cooper admitted that body snatching was happening;

> "Bodies in this country, can only be obtained at present in two ways; first, in cases where the individual has been executed for murder; and secondly in stealth" (1823 a, p.66).

He bemoaned the inadequacy of the legally available supplies, stating that between 1805 and 1820 the number of individuals who were executed for murder amounted to 1150, and that probably only half this number were ever available for dissection. With about 1000 students coming to town every year to gain a knowledge of medicine this number was obviously insufficient, and Sir Astley Cooper clearly supported the acquisition of bodies through theft;

"As long as health continues to be an object of desire, persons will be found, there is no doubt, to undertake to get bodies at any risk. The evil effects of enacting into a crime which is absolutely necessary are very serious; by that means many individuals are disqualified from keeping laws which it is desirable should be respected" (Cooper 1823 a, p.67).

In the same edition of *The Lancet* Sir Astley wrote about the inspection of a corpse which it is clear was being dissected illegally;

"The body was examined 17 hours after death, by Mr. Babington, dresser to Mr. Travers, in the presence of two or three pupils. The examination was made with such secrecy, that we were not able to be present" (Cooper 1823 b, p.234).

In one case reported Sir Astley Cooper apparently admitted receiving for autopsy bodies which had been stolen from graves;

"Old bed-ridden and fat persons (generally females), are often brought into our dissecting room with some of their bones broken (and more frequently the thigh-bone than any other) in being removed from the grave" (Cooper 1824, p.123).

There is also evidence from several cemeteries around London that autopsy was being carried out fairly regularly before the changes in the law. From Redcross Way, a cemetery site which ceased to be used in 1832 (Section 6.1.1), there were two skeletons with signs of autopsy on the bones. These included removal of the cranial vault, and sawing off the spinous process', presumably to gain access to the spinal chord.

Sir Astley Cooper's writings sometimes gave clear evidence of an appreciation of changes within the bone with ageing. Examples which demonstrate autopsy must have been carried out are given below.

"The bones of an old person may be cut with a knife, which is incapable of making any impression on them in the adult period" (Cooper 1824, p.108).

"When the bone has been macerated, its head is much lighter and more spongy than in the healthy state" (*ibid.* p.121).
"In examining the body of an old subject very much loaded with fat, in the dissecting room of St. Thomas' Hospital, I found that the gentleman who had dissected one limb, had cut through the capsular ligament of the hip-joint" (*ibid.*, p.124).

4.3 Early Text Books

Early autopsies thus gave the medical profession the opportunity to observe changes taking place with age in the skeletons of individuals being examined. From the early medical literature it appears that such changes were clearly observed and commented upon, even if the reasons for the occurrence of the changes were not well understood. One of the main features of osteoporosis is a change in the mass and trabecular structure of the bone (Section 2.3.3). Through this research it is hoped that an indication might be gained of when changes taking place in bone with age were first noticed.

Petit (1726) noted some changes in bone ascribed to various diseases, such as the 'King's evil', but it is difficult to determine if these are definitely related to osteoporosis. The bone changes he mentioned included;

> "Caries exostosis, softness, and other dispositions that render the bones more brittle" (1726, p.218).

There are several possible causes of such a condition in the bone including osteomyelitis or a tumour as well as osteoporosis. However, some of the conditions mentioned appear to have rendered the bones more liable to fracture, and Petit indicated that the bone was no longer structurally intact or strong.

> "The bony juice is not well conditioned, and.. it destroys the substance of the bone itself, and corrupts it, instead of soldering and uniting it" (*ibid.* p.226).

He described the bone with 'caries' as being;

> "Worm eaten...if the disease attacks the bones of the thigh or leg, arm or fore-arm, one may judge it very fatal, for the bones may be broken entirely, and then the limb will have no support so as that one need not lean hard upon the bone, for that might break it" (*ibid.* p.415).

This extract appears to point to fracture through minimal trauma, one of the features noted as being typical of modern fractures related to osteoporosis (Section 2.5). The areas of the skeleton he mentioned as being susceptible to such fractures are amongst those known today as classic sites for osteoporotic fractures.

John Aitken was the earliest author discovered in the present research who had observed and written about changes in bone structure with age, in his work, *Essays on several Important Subjects in Surgery: Chiefly on the Nature and Cure of Fractures of the Long Bones of The Extremities, Particularly those of the Thigh and Leg, Whether Simple or Compound; for Which* *a New Method of Retention is Proposed (1771).* He noticed that the bones of the older individuals appeared to be far more "fragile" (p.23), than those of younger individuals. Another observation made was that the bones of younger individuals and animals seemed to heal far more successfully than those of older individuals. Describing the differences between the bones of these two age groups he wrote;

> "This difference is so remarkable between these two conditions of the bones, is perhaps to be entirely ascribed to some degree of *pliancy* or *tenacity* which the bones of young animals possess, and of which they are afterwards deprived by age" (*ibid.* p.23).

He observed that there were changes in all parts of the body with age, both in hard and soft tissues, and put forward a possible reason for the increasing brittleness of bones of older individuals;

> "This great accumulation of the earthy principle in bones, would seem to be the cause producing that extreme rigidity and fragility, which those of very old people are observed to possess. To the almost total abolition of their vascular structure, may, perhaps, in a great measure, be imputed the tedious formation, and sometimes absolute defect, of callus, observable in the fractured bones of such people" (*ibid.* p.26).

The suppleness of the bones of younger individuals was put down to their greater lubrication with fluids, which he referred to as glutens. No details of the experiment mentioned in the extract below were given.

> "This quality depends almost entirely on the gluten, and is very much influenced both by its state and quality; and that the superior tenacity of young bones may justly be ascribed to the superior quality of this gluten interposed betwixt the earthy or osseous particles in their composition, which by experiment is found to be the case". (*ibid.* p.31)

> "In some cases, the texture of the bones has been so much perverted, as from the smallest violence, and even muscular effort, to suffer fracture" (*ibid.* p.38).

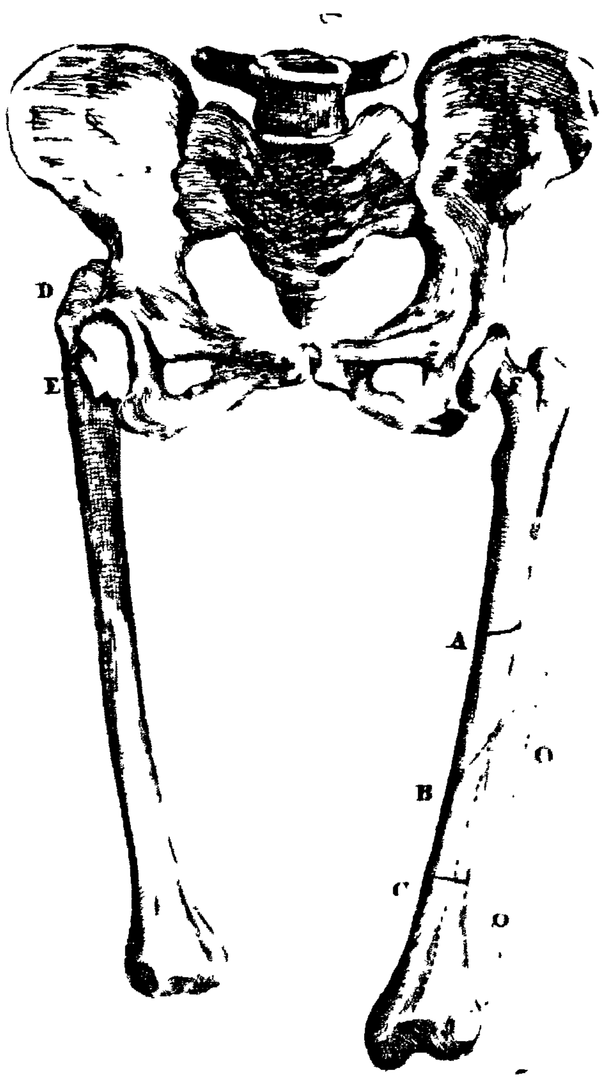


Figure 4.3.1 "Figures relating to the fracture of the thigh bone" from Aitken (1771). Permission given by the Wellcome Institute Library, London.

He also mentioned the 'spongy' (p.86) texture of bones that had fractured, and similar observations were noted by later authors. Here the changes which are observed to occur within bones are linked to ageing of the individual. It is also noted that these changes can lead to a fracture, from a low trauma incident in an elderly person. In Figure 4.3.1 various of the fractures of the femora are depicted including one (E) typical of osteoporosis, a hip fracture.

Joseph Amesbury, writing a little later, also noticed changes in bones and bone structure with age and stated the link between age, changes in bone and fractures in a clearer manner than any previously author. In *Remarks on the Nature and Treatment of Fractures of The Trunk and Extremities Vol. I* (1831) he observed;

> "The bones become brittle in proportion as persons advance in years, and in old age they are sometimes fractured by very slight causes. In childhood they are more elastic and flexible, and are not so easily broken" (p.2).

Sir Astley Cooper (1824) elaborated on the changes associated with age in bones, and described the typical alterations in bone structure seen with osteoporosis very clearly;

> "That regular decay of nature which is called old age, is attended with changes which are easily detectable in the dead body; and one of the principal of these is found in the bones, for they become thin in their shell, and spongy in texture. The process of absorption and deposition varies at different periods of life; in youth the arteries, which are the builders of the body, deposit more than the absorbents remove, and hence is derived the great source of growth. In the middle period of life the arteries and absorbents preserve an equilibrium of action, so that with a due portion of exercise the body remains stationary; whilst in old age the balance is destroyed by the arteries doing less than the absorbents, and hence the person becomes diminished in weight; but more from the diminution of the arterial than from an increase of the absorbent action. This is well seen in the natural changes of the bones, their increase in youth, their bulk, weight, and little comparative change during the adult period, and the lightness and softness in the more advanced stages of life" (p.107).

Another writer who discussed in some detail changes occurring throughout the human body, (including bones) with age was R.W. Smith, who also noticed that such changes were more pronounced in females.

> "Among all the striking and varied changes which the human system suffers under the influence of that inevitable decline of organisation, which is attendant upon advanced age, there are few more remarkable than those which affect the osseous system. These strange modifications of structure are supposed to affect the skeleton of the aged female much more frequently than that of the male" (1847, p.66).

Like Aitken (1771), Smith put these down to the presence or lack of oils in the bone though, in contrast to Aitken, he stated that it was an accumulation of oils which destroyed the structure of the bone rather than lack of them;

> "Large cavities are formed in the interior of the head and neck of the femur....we also find that the arch of compact tissue which lines the concavity of the neck of the femur, upon which the strength of this portion of the bone is mainly dependent, is in most instances reduced in thickness, and atrophied, in the aged subject....the atrophy of this arch, to a greater or lesser degree, is of common occurrence in the advanced periods of life, and to be looked for in almost every instance of intracapsular fracture of the neck of the thigh bone" (Smith 1847, p.67).

In this extract he referred to bone loss from what has come to be known as the Ward's triangle region of the femoral neck. It is the pattern of loss seen with the aid of radiographs in the region which underlies the Singh Index system (Singh *et al.* 1970) of quantifying bone loss and the onset of osteoporosis (Section 7.5.1). This area of the femur is regarded as one of the classic sites of bone loss following osteoporosis. It was so named as a result of the work of F.O. Ward (1838). He compared the arrangement of trabecular bone in this part of the femur to a triangular bracket attaching a street lamp to an upright pole. Wyman (1849) also noticed the trabecular arrangement, detailing the vertical and horizontal arrangement seen within bone sections. He suggested that the vertically oriented trabeculae resisted compressive forces, whereas those in horizontal position acted to support them. Smith further observed that it was changes in this trabecular bone which caused the bone to fracture;

> "Changes which predispose the neck of the thigh bone to fracture from the most trivial causes; under such circumstances, as has been jointly observed by Mr Adams, the fracture should in many instances, be looked upon as more a stage of morbid alteration, from which no amendment is to be expected, than as an accidental lesion, which the efforts of nature and the aid of surgery can be deemed adequate repair" (1847, p.68).

4.3.1 Bed Rest

Today one of the factors which can cause structural changes or bone loss is bed-rest or prolonged inactivity (Section 3.3.4). This is considered a problem with patients in hospital and one of the reasons why those managing treatment aim to get patients, particularly those who are liable to become osteoporotic, up and mobile again as quickly as possible. A similar effect was also noticed in the past.

> "A bone may be spongy and soft, although there be no scrophulous tendancy in the constitution. That it may degenerate into this condition, merely from want of use, will appear from observations, the truth of which will scarcely be disputed"
> (Shaw 1823, p.7).

> "It is more especially in the bodies of those who have been bed ridden for years before their death, that we notice these alterations, and will generally be found even in the adult who has been, from any cause, for years confined to bed; for long disuse produced atrophy and degeneration of the osseous system, without much respect for age, and the head and neck of the femur manifest more clearly, perhaps, than any other parts of the skeleton, the consequences of this lesion of nutrition" (Smith 1847, p.67).

All of these observations could only have been made if autopsies of patients in the care of these practitioners, or others in the medical profession, were being carried out.

4.4 Death Registers

A number of hospitals, such as St. Bartholomew's, continue to hold death registers dating back as far as the 1700's, and records relating to others institutions, such as St. Thomas' Hospital, are held at the Greater London Record Office. Early death registers give very little detail, often only the name of the individual and the date on which they died. It is only towards the end of the period of study that more detail begins to be given and cause of death starts to appear. In the death registers examined for this study cause of death was given as 'Fracture of the thigh' in a number of cases (Table 4.4.1). Many of these individuals were elderly, often in their seventies or even older, and where date of admittance to hospital is given, it can be seen that they frequently lived only a matter of months. It is suggested that the examples provided and those like them may be due to osteoporosis, when features mentioned such as the age of patient, the area of the femur and the length of time individuals survived are taken into account. Registers between 1839 and 1846 were examined. Of the cases (27) which are almost certainly osteoporosis-related 18 were from males and 9 from women. In the modern population women have a higher incidence of fractures than men. The greater numbers of men in this sample may reflect hospital admissions policy.

Examples Taken from Register of Deaths St. Bartholomew's Hospital 1839-46
1840 Jan. 9th, Martha Piper, Age 77, d. Mar 2, Fractured thigh, occ. Widow.
1840 Nov. 11th, Elizabeth Clement ,Age 72, d. Nov. 30th, Fractured thigh and arm, occ. Widow
1841 July 1st, Thomas Dickson, Age 82, d. July 17, Fractured thigh, occ. Formerly a Silk Mercer.
1841 March 1st, John Devenport, Age 82, d. July 20, Fractured thigh, occ. A Linen draper.
1843 July 30 th, Ann Beaven, Age 72, d. June 18, Broken thigh, occ. Coachman.
1843 Oct. 28 th, James Henchett, Age 69, Nov. 4, Fractured thigh, occ. Barber.
1844 Nov. 15 th, Richard Goodwin, Age 94, Nov. 20, Fractured thigh.
1845 Oct. 16 th, Mary Ann Jebb, Age 90, d. Jan 15th, Fracture to left collar bone and left thigh.

Table 4.4.1 Examples of cases of femoral neck fracture which may be due to osteoporosis, taken from the death registers at St. Bartholomew's Hospital. The first date given is the date of admission, and the date preceded by d, is the date of death.

4.5 Healing of Fractures: Difficulties

The methods employed in the treatment of fractures are very ancient, and practice has changed relatively little over several thousand years. A number of cases of fractures and dislocations are detailed in the Edwin Smith Papyrus, which was composed in 2,800-3,000 BC Egypt, and the treatments detailed in the papyrus are certainly more ancient than the document itself.

Even today, a fracture of the femur is considered a very serious injury, and bringing about a successful healing in the past would have been extremely difficult. The first description in the medical literature of an intracapsular fracture (those occurring at the neck of the femur) was that by Ambroise Paré 1510-1590 (quoted in Pettier 1990). He notes the difficulty of curing such a fracture. Many doctors were extremely reluctant to admit to the difficulties involved, but a notable exception was Sir Astley Cooper (1824). He wrote at length on the subject, admonishing those who would not admit to the difficulties. An idea of the strength of feeling on the subject can be gained from the writings of Smith.

> "It has been asserted in the strongest possible language, not only that osseous union is altogether impossible, but that there are, in the hip-joint in old people, certain provisions for the prevention of such union" (1847, p.53).

Mr Smith clearly did not accept that such fractures were impossible to treat successfully. Whilst it is not impossible that such a fracture could have healed, there would have been many difficulties. Much of the debate probably stemmed from the position of the medical profession and methods of employment and payment. Doctors being employed privately were reluctant to admit that they would probably be unable to ensure complete healing, particularly in the case of hip fractures. It is unlikely that an individual would survive and if they did would probably never walk again, or only with some difficulty. Sir Astley Cooper seems to have been more realistic in this respect;

> "I was called to a case of this fracture, in which the medical attendant had been promising, week after week, an union of the fracture, and the restoration of the patient to a sound and useful limb. After many weeks the person became anxious for further advice: I did all in my power to lessen the impression which the mistake of this gentleman had made, by telling the patient she might ultimately walk, although with some lameness" (Cooper 1824, 110-111).

Discussing the healing of such fractures Cumming similarly wrote;

> "Cases have often occurred where no union has taken place" (1806, p.236)

Surgical intervention is frequently required today to replace the joint or unite the fractured bone elements. Operations would not have been possible during this period and it was not practical even to begin experimenting with anything of this nature till the introduction of antiseptics and anaesthetics. Berrnger-Feraud (1832-1900) was the first person to work extensively on the treatment of fractures using internal fixation.

Even today such a fracture is regarded as a very serious incident. The shock to the system is enormous, and union of the ends of the bone can be difficult as a result of the poor state of the bone (see Section 2.5). The debate concerning fractured femora at that time centred around whether it was in fact possible to bring about a reunion of the femora.

4.6 Disability

That such fractures caused disability in many patients can be seen in Smith (1847, p.57) who described the case of a lady who sustained a fracture to the neck of the femur at the age of fifty. She lived a further ten years, following the accident was forced to remain in bed for a year and, when she was able to get up, was unable to walk without the assistance of crutches. Smith suggested that a union did take place in this case. Similarly Lawson Tait noticed the disability individuals could be left with following poor treatment for Colles' fracture.

> "Within the last three years twenty cases have come under my observation where this fracture had occurred, had not been properly treated and has left its characteristic hideous deformity" (1867, p.1107).

> "The power of pronation is almost gone, the hand is rapidly becoming atrophied and is so weak that it (the left hand) is almost powerless over the reins....Such cases are only too common" (*ibid.* p.1108).

> "Last year I dissected the arm of a woman in whom the deformity was excessive. In her case the fracture had been recognised and very promptly put up by a competent practitioner, but another happening to pass the house shortly after was not on good terms with the first, he was called in to examine the case, failed to detect the fracture, declaired that it was a sprain and that the splints were useless. The result was that after three months the hand was utterly useless, and remained so until the patient died" (*ibid.* p.1108).

> "It is in old people that this immoderate deformity is most frequently observed" (*ibid.* p.1109).

Speaking of the case of an old man who was treated with straight splints he wrote;

> "Now the hand is almost useless, pronation and supination almost entirely lost, the hand and arm very much atrophied and always presenting a cold blue miserable appearance" (*ibid.* p.1109).

4.7 Treatment of Fractures

Lawson Tait stated that splinting should be used in all cases of suspected fracture of the wrist, even if precise diagnosis was not possible immediately, because it would do a sprain no harm to be treated in this way. It was important to obtain accurate replacement of the fractured ends and then the area needed to be kept entirely motionless. Details of the treatment applied to femoral fractures were given in the Edinburgh Medical Journal 1866-67. This is slightly later than the period covered by the study but treatment described here is probably similar to that undertaken between 1700 and 1850. Where the femur was fractured within the capsule the treatment aimed to keep the bone and fragments in place, and it was recommended that the patient had complete rest in a horizontal position. The limbs should be;

> "Secured in straight splints....this apparatus possesses also this advantage, namely, that it presses the broken fragments more firmly against each other, and thus operates to prevent their displacement in the direction of the axis of the shaft" (p.378-9).

It was stated that this position was more comfortable for the patient.

> "I am prepared to affirm, from my own experience, that more patients will endure quietly this position for a length of time than the flexed position .... how long the patient will submit to this, or to any other mode of securing perfect rest, is very uncertain, and the decision of this question must rest with the individual cases and the good sense of the surgeon. Not very many old and feeble people will bear such confinement many days without presenting palpable signs of failure as to demand complete abandonment" (p.379).

Cases taken from Mr Liston's case notes for the N.L.H. Surgical Cases Female Wards, also illustrate details of the treatment being administered. He described the case of an elderly lady who was brought in suffering from both a fractured femur and a broken arm after an accident involving a fall.

> "The thigh was placed in a long splint and the arm was kept extended by a splint placed in front. Long splint was taken off the patient complaining so much of pain - and was placed on the water bed to very much emaciated, is unable to void, her urine which was drawn off" (1834, p.56).

Fracture of the femoral neck is still regarded by many in the medical profession in the same terms as those described by Cumming.

"This is the most difficult fracture to manage in the whole body, and what surgeon is there who in the course of his practice has not witnessed the most unpleasant consequences resulting from it?" (1806, p.243).

4.8 Mortality

One of the features which has focused so much attention onto osteoporosis recently, is the very high mortality which fractures can produce (Section 3.2), and one of the aims of the current research was to assess whether or not past populations were similarly affected. Although many people survive the actual fracture, they die within a relatively short space of time, and today, one in four women who sustains an osteoporotic fracture dies prematurely (Stevenson *pers. com.*). Most individuals who experience an osteoporotic fracture are elderly. The shock of a serious accident such as a fractured hip seriously weakens them, leading to greater susceptibility to many other conditions, such as pneumonia, which are the ultimate cause of death. This is evident in many of the cases collected in Appendix I.

> "Sometimes the patient dies in a few days from the effects of the shock upon a system already enfeebled by age; very frequently bronchitis sets in, and terminates fatally before ten days have elapsed" (Smith 1847, p.65).

> "Of five compound fractures of the femur, only one recovered. These were most severe. In the case of a female aet. 71, traumatic gangrene followed the hurt, and proved fatal in fifteen days" (St. Bartholomew's Hospital Reports; 1865 Vol. 1 p.50).

R.W.Smith similarly depicted a case of fracture of the neck of the femur in an elderly female patient (over 80) who, "Died eight weeks after receipt of injury" (1847, p.106).

One of the traumatic effects noted today in cases of fracture of the femoral neck is internal haemorrhaging. Patients admitted to hospital today with such a fracture are often immediately given a blood transfusion to help cope with the loss of blood which can be as much as two to three pints (Section 2.5.1). Such loss of blood would undoubtedly weaken the patient, especially the elderly, and this effect of femoral fractures was noticed during the period under study.

> "Sometimes, as in the instance detailed by Cruveillier, elsewhere alluded to, death is to be ascribed to the occurrance of profuse haemorrhage into the substance of the limb. The blood is poured out from the torn vessels of the cancellated structure and occasionally also from some arterial branch of considerable size, that has been lacerated, or punctured, by a spicule of the broken bone: finally, in patients of very advanced age, and where proper precautions have not been adopted, sloughing of the integuments of the nates and trochantic regions occurs, and very soon places the patient beyond the possibility of recovery" (Smith 1847, p.66).

The hastened death from shock and loss of blood is commented upon by Smith.

> "patient dies in few days from effects of shock. Breaking of blood vessels etc". (Smith 1847, p.65);

4.9 Changes in Terminology

Recent advances in medical science have brought about changes in the terminology applied. What would today be referred to as a hip fracture or fracture of the proximal femur was, during the period (1700-1850), called a fracture of the thigh. This term seems to have been used only to describe intra-capsular fractures of the femur, the type of fracture which today is commonly associated with osteoporosis. Cooper, when writing of hip fractures, referred to them as a "Different species" (1824, p.101).

In a similar way terminology for features of the bone and its structures was tightly defined only quite recently. During the period of study, the terminology used was far less rigid. Many individuals developed their own descriptive terms to report features of the cases under investigation. However, it is usually possible to gain a reasonable impression of what is being described.

4.10 Case Notes

Doctors' hand writing was no better in the period under study than it is today but, once deciphered, case notes can be a valuable source of information. As mentioned above, hospitals were funded and run in a different way from modern hospitals. In many instances much effort was put into detailing the good character of the individual, rather than describing their condition, but useful information can often be gained. In some cases there may be details such as the age and sex of the individual, the type of fracture, the circumstances under which it happened, the treatment given and the outcome of the case. There are also collections of case notes dealing with fractures, made by interested individuals wishing to share information with others in the medical profession and thereby further knowledge of the subject

> "Mary Clement, aged eighty-three and a half years, when walking across her room, October 1 st 1820, supported by her stick, which from the debility consequent upon her age she was obliged to employ, unperceived by herself, placed her stick in a hole of the floor, by which loosing her balance, and tottering to recover herself from falling, which she would have done but for those near her, she found she had, as she supposed dislocated her thigh-bone. When called to her she was lying upon her bed in much pain, with the thigh shortened and the foot everted. 'Examination' which fully confirmed me in the opinion that some part of the neck of the femur was broken" (Cooper Case I,1824, p. 139).

4.11 Features Associated with Fractures

As discussed earlier (Sections 2.6) a common feature of osteoporotic fractures today is the low level of force (trauma) which is required to produce them. Sir Astley Cooper noted the comparatively normal circumstances surrounding many of the hip fractures which he encountered.

> "That this state of bone in old age favours much the production of fractures, is shewn by the slightest causes often producing them. In London the most frequent source of this accident is from a person, when walking on the edge of an elevated footpath, slipping upon the carriage pavement; and though it be a descent of only a few inches, yet, from its occurring so sudden and unexpectedly, and from the force acting perpendicularly, with the advantage of a lever in the cervix, it produces a fracture of the neck of the thigh bone; and as the fall is the consequence of this fracture it is imputed, by ignorant persons, to the fall, and not to its true cause" (Cooper 1824, p.109).

The lack of understanding amongst the medical profession of biological processes operating to bring about fractures such as the hip fracture illustrated by Amesbury, Figure 4.11.1;

> "Some gentlemen might argue, that the appearances which these preparations present might be produced by disease, I have not however, seen any specimen which would incline me to favour such an opinion; and would enquire if disease was ever known to produce, suddenly, in a person, in every respect previously healthy, the symptoms of fracture of the cervix femoris" (1831, p.135).

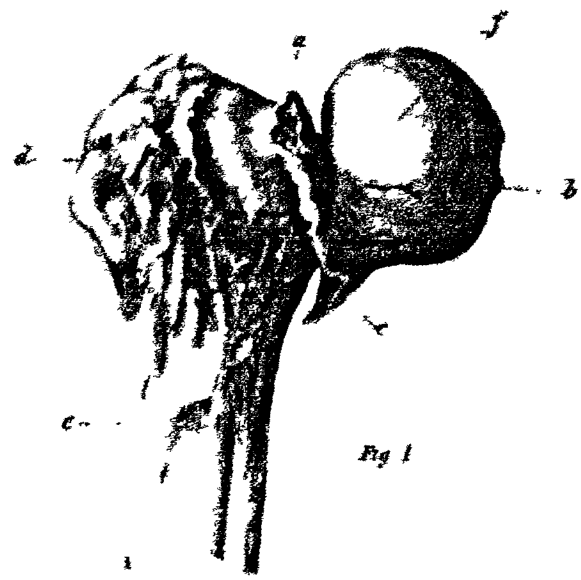


Figure 4.11.1 "The anterior surface of the upper and external part of the femur" Amesbury (1831). By permission of Wellcome Institute Library, London.

The slight trauma required to produce a fracture is evident when reading many of the cases gathered, listed in Appendix I.

4.11.1 Age at Which Fractures Occurred

The age at which a fracture of the type illustrated by Cooper, Figure 4.11.2, occurred is also an important factor, because development of osteoporosis is strongly linked to age (Section 2 and 3). Cooper made a number of observations about fractures which came to his attention which indicate that the propensity of older individuals, particularly females, to sustain certain types of fracture was widely accepted.

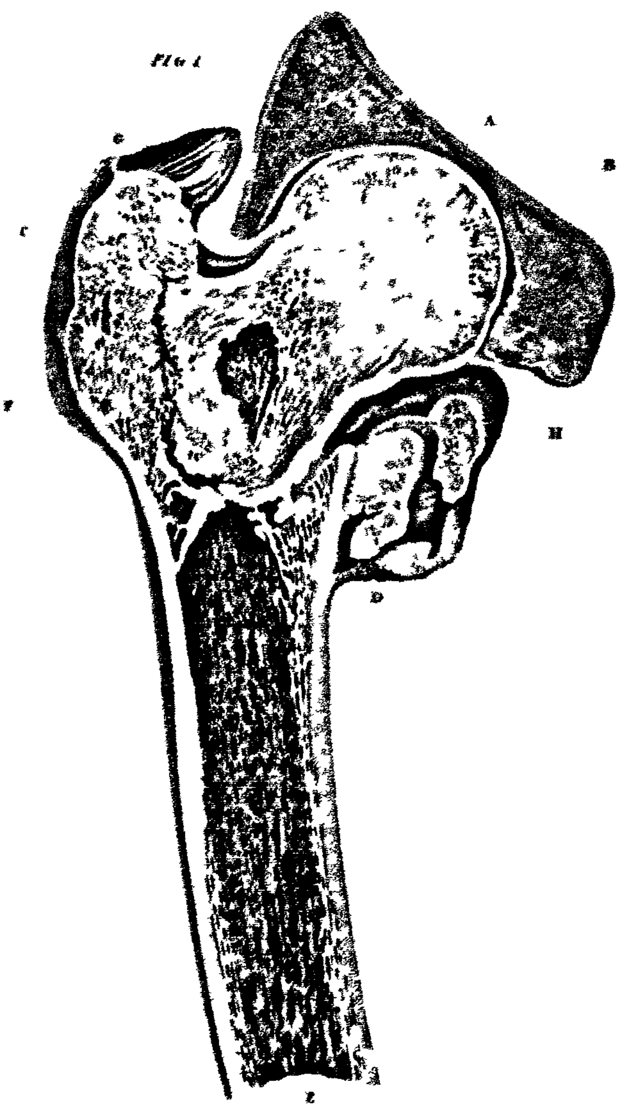


Figure 4.11.2 "Fracture of the neck of the cervix femoris, given me by Mr Powell, surgeon, of Coram-Street, Brunswick-Square, in which the neck of the thigh bone has been forced into the cancellated structure" Cooper (1824). By permission of the Wellcome Institute Library, London.

> "Women are much more liable to this species of fracture than men; we rarely in hospitals observe it in the latter, but our wards are seldom without an example of it in the aged female....the fracture of the neck of the thigh bone within the capsular ligament, seldom happens but at an advanced period of life, whilst the other fractures I have described happen at all periods of life. Old age, however is a very indefinite term; for it is as strongly marked at sixty, as in others at eighty years." (Cooper 1824, 106-7).

Sir Astley went on to define in unambiguous terms the exact ages at which these fractures arose, and the ages he gave clearly match those encountered in modern cases of osteoporotic fracture.

> "Between fifty and eighty years is the most common period at which the fracture occurs" (Cooper 1824, p.109).

Joseph Amesbury also showed that the link between old age and the minimal trauma fractures were understood.

> "The immediate causes of fractures of the neck of the thigh-bone in old people, especially those which occur within the capsule, are often very slight, such as a slip of the foot from the curb-stone down upon the carriage road when the weight of the body is upon the slipping limb" (1828, p.7).

> "In old age they are sometimes fractured by very slight causes" (1831, p.2).

4.11.2 Frequency of Fractures

The nature of the historical records available, makes it impossible to obtain a precise figure for the frequency of fractures, and even with modern hospital records there are many difficulties involved in calculating the present day prevalence (Section 3.2). It can, however, be seen that they were frequent enough to arouse a great deal of interest in doctors and surgeons of the period.

> "These accidents are far more frequent than dislocations of the thigh bone; for whilst we receive into our hospitals of Guy's and St. Thomas's (containing about nine hundred persons), not more upon average than two such dislocations in a year, our wards are seldom without an example of fracture of the upper part of the thigh-bone" (Cooper 1824, p.101).

> "I cou'd give great numbers of examples of this sort" (Petit 1726 p.314).

Some attempt to quantify the number of femoral fractures occurring annually was made by Cooper.

> "I have now been thirty-nine years at St. Thomas's and Guy's Hospitals; and for thirty years, have had more than my share, and much more than I mentioned, of the practice of London. We have eight hundred and fifty patients in our two hospitals; and I believe that in the two hospitals, eight cases of fractures of the upper part of the thigh-bone occur in each year" (Cooper 1824, p.109).

It has been noted that fractures occur more frequently in the winter (Barlow 1994) and this may also have been the case in the period under study.

> "An intensely cold or frosty state of the atmosphere has been thought, in like manner, to render the bones more than ordinarily fragile. The frequency of fractures during frosty weather, seems to have given rise to this opinion;- the greater slipperiness and hardness of the earth in this than in soft weather, the one occasioning more falls, and the other fractures account for this fact independent of the notion of increased frostility" (Aitken 1771, p.40).

4.11.3 Femoral Fracture

Femoral fractures received the most coverage in the literature consulted. In view of what is known about the condition and its consequences from modern cases, this situation is not remarkable. There would have been little that could have been done, and the pain, disability and probable death of patients would have been a major source of concern. This type of fracture is covered in detail by the examples given above so they will not be repeated here.

4.11.4 Colles' Fracture

The literature of the period which relates to Colles' fractures is not as extensive as that relating to fractures of the femur. Colles' fractures occur throughout the age range, but prevalence varies with age with higher levels in slightly younger individuals. The associated morbidity and mortality is not so great as that associated with femoral fractures. There would, however, have been some risk attached, most probably of deformation of the wrist. In the Pathology Museum of the Royal College of Surgeons there are many records relating to cases of Colles' fracture from which specimens had been collected. A note accompanying the cases indicated that these fractures were quite frequent, but not normally life threatening.

> "These hurts are important....if only from the frequency of their occurrence" (St. Bartholomew's Hospital Reports Vol. I 1865, p.281).

In the report on a case of Colles' fracture given below the discomfort, pain and possibility of deformity are clearly illustrated.

> "A female aet. 51, came to my out-patient room with a fracture of the carpal extremity of her right radius, of four weeks' duration. The forearm had been kept continually at rest, in the prone position, on a straight splint. For the last week she had been directed to use the wrist twice daily. She complained of pain about the seat of the fracture, and of considerable deformity. The bone had been broken across about three-quarters of an inch from the carpus and the distal fragment formed a well-marked projection on the palmer aspect; on the dorsal the proximal end was of course prommenent. The wrist was fixed, and half the rotation of the radius was lost, that is to say, there was no movement beyond that which placed the thumb uppermost from extreme pronation. By long-continued passive movements her condition was somewhat improved, so that flexation was exaggerated, extension was, in the end, less complete than natural. The bone deformity persisted"
> (St Bartholomew's Hospital Reports Vol. I 1865, p.281).

The reason why fractures occurred at this exact point of the bone appears to have been relatively well understood. Autopsy examinations almost certainly aided the development of such knowledge.

> "In its ordinary adult state, the carpal end of the radius consists, almost entirely, of cancellous tissue, nor are the bone plates arranged on any such plane as would add to their strength.... when the shaft of the radius has to resist, as with falls upon the hand, a violent shock transmitted in the line of the long axis, the weak cancellous tissue is broken across and the wedge-like end of the compact wall is driven into the distal portion of the bone".
> (St Bartholomew's Hospital Reports Vol. I 1865).

> "Fractures in every part of the radius below the tubercle are very common, it is thought more so than fractures of the ulna" (Amesbury 1831, p.590).

The impact of Colles' fracture on the population of the period would, to a large extent, depend on the way such fractures were treated. There would have been strong personal and economic consequences if the wrist was set badly, leading to restricted use of hand. Colles' fracture occurs at an earlier age, and many individuals would still have been working but would also be better able to overcome the trauma. Many of the occupations listed as being carried out in parish records from Farringdon Street and Redcross Way such as labouring or bricklaying, would have been impossible to carry out with a deformed wrist and impaired movement.

4.11.5 Vertebral Fracture

It was impossible to discover firm evidence for osteoporotic vertebral fractures in the literature reviewed. This was to have been expected because vertebral crush fractures can be virtually symptomless and may be caused by something as slight as coughing (Section 2.5). The lack of reference, therefore, simply reflects their nature. Thus the ability of those in the medical profession to diagnose and treat this type of fracture, would account for the scarcity of references in the literature. Even today it is only in extreme cases that medical intervention is undertaken (Section 2.5.2). It was accepted, however, that elderly individuals became shorter and often suffered a curvature of the spine, a 'widow's hump'.

T. Petit (1726) described one condition as producing "softness" (p.1), deformation and curvature of the spine;

> "The shape of the body is deformed because the spine no longer retains its usual uprightness...spine being no longer straight, the weight of the body is not upon the line of gravity; and because if the patient tries to replace it there (as hunch back'd people do) in order to walk, all the motions he makes, are so many shocks, which shake and press the spinal marrow and cause violent pains" (p.53).

It is hard to know if this example describes a vertebral crush fracture, bearing in mind his mention of 'hump'd backed' people, but it seems reasonable to assume that one possible cause might be osteoporosis-related spinal crush fracture.

Writing of Cooper's work on fractures, Sir Charles Bell commented;

> "He had omitted to observe, that fractures of the spine like fractures of the other bones of the trunk, are most frequent in old labouring men" (1824, p.26).

4.12 Discussion and Conclusions

Overall it would appear that osteoporosis did present a problem to the population and medical practitioners of the period, although it is not possible to be certain that the cases discussed in the literature are in fact osteoporosis. One possible way in which it could be discovered if the cases reported in the medical literature were in fact due to osteoporosis is to examine specimens held at pathology museums such as those of the Royal College of Surgeons and St. Bartholomew's Hospital. In medical writings of the period specimens were referred to as examples of the changes in bone which were being discussed. It was mentioned in a letter to Sir Astley Cooper that the author Edward Stanley (Appendix I), considered the specimens held in the Pathology Museum at St. Bartholomews' to be similar to those written about by Sir Astley Cooper (Cooper 1824, p.494). However, enquiries at the museum revealed that many specimens were destroyed during the Blitz, and sadly the fractured bones were amongst those which had perished. It is reasonable to conclude that. In spite of these difficulties, the pattern which is seen to emerge from the early medical literature mirrors that reported for osteoporosis today, it was predominantly older people who were affected, with women more frequently affected than men;

a) those who suffered a Colles' fracture did so at an earlier age than those who suffered femoral fracture;
b) many of the fractures were sustained after a low energy impact;
c) there were clearly observed changes in the structure of trabecular bone, which occurred as an individual aged;
d) although, unfamiliar terminology is used to illustrate the changes taking place, what is described sounds like the bone loss and structural change associated with osteoporosis today.

The great debate surrounding the treatment of femoral neck fractures, and the concern about the problems encountered in trying to get such fractures to unite, suggests that they constituted a serious problem and must have been reasonably common for so much time and energy to have been devoted to them. It is also clear from the writings of the period that there was a great deal of pain and disability associated with such a fracture, as is the case today. Morbidity was also a problem and it is clear that many individuals never recovered from such a fracture.

As today, the other two sites commonly associated with osteoporotic fracture are given less coverage. Neither Colles' fracture nor crush fracture of the spine are as traumatic for the individual as femoral fractures, and few patients with vertebral fractures would be aware that they had taken place. Such a fracture can lead to severe back pain lasting up to six weeks but this is not always the case and pain will normally disappear with no treatment. There are numerous problems associated with quantifying precisely the incidence of fractures even at the present day (Section 3.2), and it is not possible to quantify them for the period covered by this study. All that can be concluded is that osteoporotic fractures were sufficiently common to be widely noted by the medical profession. There would have been a significant impact on individuals who sustained such a fracture and their families and, during this period before state provision, individuals would have been supported within the family. It would have been viewed as a last resort to allow a member of the family to be taken into an institution, and there would have been many who were cared for in the home.

5. Studies of Osteoporosis and Age-Related Change in Archaeological Material.

5.1 Introduction.

Greater awareness of osteoporosis has led paleopathologists to address the question, 'Were past populations similarly affected by this condition?' Such questions were prompted by a heightened appreciation of the morbidity and mortality caused by osteoporosis-related fractures. A variety of approaches have been used to assess bone loss and osteoporosis in archaeological bone material, the least technical being the examination of archaeological bone for evidence of fracture. Conflicting results have been reported, for example González-Reimers and Arnay-de-la-Rosa (1992) reported that osteoporosis was present in a prehispanic Canary island population studied. However, a review paper by Agerwal and Grynpas (1996) concluded that osteoporosis was not prevalent in the past.

Archaeological specimens which display fractures typical of the type caused by osteoporosis may be excavated, and are beginning to be reported paleopathological literature (Dequeker *et al.* 1997, Foldes *et al.* 1995, Frigo and Lang 1995, Mays 1996, Roberts and Wakely 1992). One such specimen, discovered during excavations at the Roman site of Pella in Jordan exhibited a fracture characteristic of osteoporosis (Sambrook *et al.* 1988). The bone, a lower thoracic vertebra of a mature (50-60 year old) male, displayed a wedged deformity typical of an osteoporotic crush fracture. A fracture of this nature is unlikely to have occurred during burial or excavation. However, with fractures in other regions of the skeleton, there may be an element of doubt about the origin of the fracture if it had occurred a short time before death. There is the possibility of fragmentation of bones prior to burial through rough handling of the corpse. Bones may also become broken in the ground. As Ortner and Putschar (1985) observed, it can be extremely difficult if not impossible to make a distinction in archaeological material between fractures which occurred close to the time of death and soon after burial. A list of criteria which may help in the determination of when a fracture occurred was given (*ibid.*). For example, if a fracture occurred before death, provided the bone is carefully excavated it may be possible to observe fragments of bone which may have been adhering to the periosteum, though this rarely survives. Another indicator of when a fracture occurred is the presence of staining of the fractured surface of a bone. As such staining often occurs during burial, fractures occurring before death are more likely to be stained. Breaks occurring after burial may be lighter in colour than other bone surfaces but those which occur as a result of excavation will in many instances appear much lighter. However, care must be taken as staining of bones in the ground can be highly variable.

Not all bones that have undergone significant loss and structural changes within the trabecular region, making the individual prone to osteoporotic fracture, will do so during the individual's lifetime (Jayasinghe 1991). A spectrum of bone loss occurs throughout the skeleton and even within specific bones. It is therefore not possible to rely on examination of the external bone surface, to gain a complete picture of bone loss and osteoporosis in a past population. Techniques to detect the presence of bone loss and osteoporosis either need to be invasive, or to produce an image of the internal structure, or to generate some measure of bone mass or density.

5.2 Cortical Bone Changes

Many of the initial studies undertaken to investigate the past prevalence of osteoporosis and patterns of bone loss employed cortical thickness measurements. Measurements of the thickness of the cortical bone of various skeletal elements have been calculated, either directly from cut sections or analysis of radiographs (Carlson *et al.* 1976, Ericksen 1976, Martin and Armelagos 1979 and Mays 1996).

One such study was carried out on humeri and femora obtained from three collections of Native American material; Alaskan Inuit, Pueblo of the Southwest and Arikara of South Dakota. Radiographic measurements from whole bones, and direct measurements of cortical bone obtained from cores removed from some specimens were made (Ericksen 1976). Measurements were taken from the mid-shaft of the femur, and from the region immediately below the tuberosity of the humerus. Corrections were made for body size. It was stated that trabecularized endosteal bone was excluded from measurements from radiographs, but such bone cannot be distinguished from original trabecular bone even by direct observation. From the results obtained it was stated that bone loss in the humerus and in the femur was observed to begin during middle age (30-50 years) in all three populations. By middle age females were observed to have lost twice as much cortex as males.

Thompson and Gunness-Hey (1981) made a similar study of archaeological Inuit and other early North American material. Bone cores were taken from the anterior femoral mid-shaft of sample material and analysed, and the cortical thickness in males was observed to be significantly greater than that in females. No adjustment was made for size in this study. A collection of material from Sudanese Nubia (A.D. 350-550) was studied to assess bone loss by Martin and Armelagos (1979). Sections of the femur were microradiographed and cortical thickness was measured from these. It was claimed that formation and resorption patterns could be determined through measuring contrasts in density: however, this is unlikely in archaeological material using this technique. Microradiographs are not an efficient way of gaining information on bone. Slight variation in section thickness, which is very difficult to control in archaeological material, will introduce error. As a result of the problems involved with microradiographs such techniques have been largely superseded by the advent of backscattered imaging in the scanning electron microscope, which has been shown to be much more suitable for application to archaeological bone (Bell 1990) and such studies of modern bone material (Kingsmill 1996). However, even using this technique, care must be taken though as error may also be introduced as a result of diagenetic change. Martin and Armelagos reported that measurements made from the microradiographs revealed bone loss with ageing, with females loosing a greater amount than males. However, the authors define osteoporosis simply as cortical bone loss, which is not adequate. Cortical thinning is only one aspect of bone loss observed with osteoporosis (Section 2.3) and there is no 'standard' for osteoporosis related to cortical thickness.

Carlson *et al.* (1976) studied cortical bone loss in an Amerindian population dated A.D. 1540-1700, excavated from the Campbell Site in southern Prescott County, Missouri. Measures of the cortical thickness were taken at eight points around the femoral shaft from five sections cut at intervals along the femur. The cross-sectional area and diaphyseal diameter were obtained through a point counting technique. The results revealed that cortical loss with age was greater among females than males. In this study, loss of cortical thickness was once again referred to as an indicator of osteoporosis. British archaeological material has also been studied for bone loss. Mays (1996) undertook a study of cortical bone loss with age on British Medieval material from the site of Wharram Percy. It was stated that if surface erosion was apparent in a sample, then that bone was excluded from the study. Radiographs of the second metacarpal were obtained, and the cortical index calculated from measurements taken from the images to assess bone loss. The cortical index gives the percentage of bone width taken up by the cortex. The results indicated that there was significant bone loss with age in the females but not the males. Possible osteoporotic fractures were found predominantly in individuals with a low cortical bone mass.

Care must be taken when obtaining information from radiographs, as inaccuracies may be introduced, for example, through variation in the exposure and development of films (Section 2.4.1). However, diagenetic changes should only play a minimal role in measurements of cortical thickness taken from radiographs, and direct measurements taken from bone sections. Changes such as delamination undoubtedly occur during burial, but samples in which such loss is apparent can be excluded from study (Mays 1996). Errors introduced through slight cortical loss would probably be within the measurement error range. This gives such techniques an advantage over some others discussed in this section. Radiographs can be used to assess simply the mineral density of the bone through calculation of equivalent thickness of a standard (Cosman *et al.* 1991).

5.3 Computerised Tomography

Computerised tomography (CT) has not been widely applied to the problem of bone loss with age in archaeological material. This is probably because the equipment is extremely expensive and is only found in major hospitals, so that access for non-medical use is very restricted. For its successful application and the production of accurate results it also requires a full collaboration with a radiologist who is able to devote a considerable amount of time to the project. The technique was utilised in a study of three groups of archaeological material from the American South West, Early Villagers (A.D. 500-1150), Abandonments (A.D. 1150-1300), and Aggregated Villages (A.D. 1300-1540) (Brock and Ruff 1988). Variation in the shape and thickness of the femoral cortex between the groups was investigated. Bone density was calculated from attenuation data, though no information had at the time been obtained for the possible influence of diagenetic changes on bone density. Individuals from a period of settlement abandonment (Abandonment Period) were reported to have a lower bone density than individuals from the other periods. No mention was made of age- and sex-related differences in bone loss, the way in which cortical bone loss relates to density, or of artifactual problems associated with clinical imaging techniques. These artifactual problems apply to studies of both modern and archaeological bone. Even with sophisticated techniques such as CT, definition of cortical bone is highly suspect, and 'trabeculae' may be artifactual. For example, lumbar vertebral bodies have shell-like cortices no more massive than most trabeculae (Jayasinghe *et al.* 1994), and yet all the clinical imaging methods show a thick cortex. CT is, however, non-invasive, which can be a great advantage when dealing with archaeological material, allowing examination of bones which might not otherwise be available for study because of rarity and concerns over allowing sections to be taken.

5.4 Dual Energy X-ray Absorptiometry (DEXA) and other Photon Absorptiometric Methods

Dual energy X-ray absorptiometry (DEXA), a widely used clinical diagnostic tool (Section 2.4.4.2), is also increasingly being used on archaeological bone material. One of the first studies to use this technique was that undertaken by Perzigian (1973 a and b). Two Native American populations were examined, Indian Knoll (2500-2000 B.C.) and Pete Klunk (50 B.C.-250 A.D.). Bone mineral density was observed to be slightly lower in the former group. From this it was concluded that one group had better levels of nutrition. Females from both samples were reported to lose more bone than males, as in modern populations (Perzigian 1973 b). No consideration was given to the possibility that diagenetic change, and any effects of differences in soil types and ground water processes between the two sites might have had on the results. Care must be taken when using non-invasive techniques, as post burial changes may have occurred, particularly in comparisons between populations, from different sites,

Nelson (1984) looked at bone density in three American archaeological populations separated in time and space; an Archaic and early Woodland sample from Carrier Mills III, a sample from the Larson phase at Dickson Mounds III, and one from the Fletcher site. Photon absorptiometry was applied and cortical thickness was measured, allowing an index to be obtained by dividing bone mineral density by cortical thickness. This index was used to calculate differences in cortical loss between the groups. As in the above studies, no mention was made of the possibility of diagenetic change influencing bone density results.

DEXA was also used to analyse the vertebra (Section 5.1) found at Pella, Jordan, which had shown evidence of a crush fracture (Sambrook *et al.* 1988). The figure obtained for bone mineral density was considered to be very low in comparison to modern clinically derived data, whatever the age and sex of the individual. A normal DEXA machine designed for clinical applications was used and there is no mention in the report of soft tissue replication. It was stated that, "Bone density measured by dual photon absorptiometry in dried, marrow free vertebrae appears to be directly comparable to measurements performed in living subjects" (p.168). This is certainly not the case (Section 2.4.4.1). Frigo and Lang (1995) used data from DEXA analysis to compare the bone mineral density (BMD) of individuals taken from across an archaeological site, but made no mention of possible diagenetic change.

Bennike and Bohr (1990) analysed archaeological bone material from three different sites, using a dual photon scanner to measure the bone mineral content of the femoral shaft and neck. A comparison with modern material was made using 6cm long sections of femoral mid-shafts which were obtained from 45 autopsy cases of known age and sex. No details were given about the autopsy material. For example, it was not reported whether the material was cleaned of all soft tissue. The average values for bone mineral density were observed to be significantly higher in the Neolithic groups than in those from the Viking period and middle ages. Bone mineral density values of the recent material lay between the latter two groups. No mention was made of age- and sex-related differences in density in any of the groups analysed, but some consideration was given to possible changes in bones after burial. Scans were made of both femora from the same individual, and from different regions of the bone. Highly significant correlations were demonstrated between the right and left femoral shafts and necks of individual bones, and these findings were used to suggest that no mineral changes had occurred. However, such methods are not adequate to rule out the possibility of changes having taken place. There will be a slight variation between the left and right bones of an individual and there are differences in density between different regions of a bone. This was during preliminary work on the Redcross Way sample material; many individuals had a larger bone on one side of the body than the. There are also limitless possibilities for ways in which diagenetic changes might have altered the bone. Such factors will influence the results obtained from scans, complicating interpretation. The statement that diagenetic changes would be expected to be broadly similar between areas of the same bone although somewhat irregular in its exact effects is not correct (Section 7.4). Without undertaking an analysis of the mineral composition the possibilities of changes having occurred cannot be ruled out.

Raptis (1992) evaluated the reproducibility and validity of applying DEXA to archaeological bone, particularly with regard to its use in the detection of osteoporosis in archaeological bone. Significant agreement was found between the measurements made on bones by different workers. This simply demonstrates that reproducible results can be obtained from DEXA equipment, a fact already known, hence its present clinical use. Statements by the author such as "osteoporosis results in loss of the skeletal mass without alteration of the composition of bone" (Raptis 1992 p.119) suggest that the process of osteoporosis was misunderstood. This statement could be taken to mean several slightly different things, but whichever way it is interpreted it is not entirely correct (Section 2.1 and 2.2). In view of the work where it is shown that bone mineral density is not directly proportional to the compressive strength of bone, (for example, Mosekilde and Mosekilde 1986) density data should be treated with caution (Section 2.3.3). A better assessment of the usefulness of the technique would examine the relationship between BMD produced with DEXA and trabecular structural integrity. Raptis did consider diagenetic change, and made a chemical analysis of the bone with an atomic absorption spectrometer. He compared concentrations of calcium in the soil with those of the bone, and concluded that no change had occurred, as calcium content derived from chemical analysis correlated with absorptiometric data. His reasoning is unclear, and does not appear to answer questions about possible diagenetic change. No data on levels of bone mineral density or variations with age and sex were given, as this was not the aim of the work. The structural competence of the trabecular bone appears to be vitally important in the prevention of fracture, and therefore a study which uses only DEXA cannot hope to demonstrate the validity of the technique for the diagnosis of osteoporosis. For this to be done DEXA data would have to be tested against results produced from structural analysis.

A DEXA analysis of skeletal material from the crypt at Spitalfields London (Lees *et al.* 1993) concluded that women in London during the time period under study (A.D. 1700-1850) had a higher bone density than modern day women, and did not start to lose bone till a later age. It was suggested that one possible factor may have been higher levels of physical activity in the earlier population than those of today. The fact that the results for bone mineral density obtained from archaeological bone were not suitable for comparison to data obtained from living patients was realised, and in order that an idea of the levels of bone loss taking place within the population could be gained, results were expressed as a percentage of the mean value found in the young normal subjects from each group. However, no consideration was given to the possibility that bone from some individuals may have undergone diagenetic change, despite the fact that the site publication reported that the same skeletons had been contaminated by metal elements from coffins in the crypt (Molleson *et al.* 1993). When looking at lead levels in bone as part of a study of diet "evidence for the post-mortem uptake of heavy metals emerged" (*ibid.* p.17). Other metals were also observed to have been taken up by the bones: there were "high levels of iron indicated by the spectra for an infant (*ibid.* p.2247)". Only infants and juveniles produced anomalous radiographic images, but this does not rule out the possibility that adult bones were also contaminated to a lesser extent.

González-Reimers and Arnay-de-la-Rosa (1992) calculated trabecular bone mass in 99 ilia from prehispanic archaeological material from the Canary Islands using a Leitz ASM semiautomatic autoanalyser. No details of this technique are provided in this paper. A range of normal bone mass was assembled using the results of studies on modern bone material. and this was compared to data obtained from the archaeological bone. It was stated that diagenetic change was not a problem as the skeletal material had not been buried, but was from cave sites. Diagenesis was not tested for and this is not a safe assumption. It was reported that there was a large range of trabecular bone mass results produced within each age group for the ilia examined in this study. Based on this work they suggested that the prevalence of osteoporosis may have been as high as 20% in the older individuals

Techniques such as DEXA were developed for clinical use. As a result, there are problems involved in their application to archaeological bone. The possibility that diagenetic change may have taken place in archaeological bone should always be addressed when undertaking non-invasive studies of bone. Non-invasive investigative techniques such as DEXA calculate a figure for the physiological 'bone mineral' (mostly hydroxylapatite) content of the object being scanned, but the equipment cannot distinguish between different minerals. If a lump of lead were scanned, the equipment would calculate the density of hydroxylapatite in the scanned object! In addition it is now understood that there is a large and continuous range of bone mineral densities over which an osteoporosis-related fracture might occur.

5.5 Scanning Electron Microscopy

Roberts and Wakely (1992) carried out a study of archaeological vertebral sections using scanning electron microscopy. With such a method the whole sample cannot be observed in one focused view, but it is possible to identify microcallus formations in the trabecular bone. In such circumstances microcallus identifies areas in which microfractures had occurred. Damaged areas of this nature are often observed in individuals with osteoporosis (Jayasinghe *et al.* 1994), and such features indicate a collapse in micro-architectural integrity of trabecular bone. Pictures have to be obtained of a 'significant' area of the cut trabecular bone in order that an accurate assessment might be made of trabecular structural integrity. Differences in the structure of the vertebral trabeculae in individuals of different ages were also seen. In older individuals trabeculae were very fine, with vertical trabeculae thicker and more numerous than horizontal ones. Some trabeculae had rounded ends; these are products of ante-mortem bone resorption, and are characteristic of bone loss. Material of both Medieval and Romano-British date was examined by Roberts and Wakely (1992) in this way. Evidence for osteoporosis was discovered in several older (over 50 years of age) males but no indication was given of how individuals were categorised as being osteoporotic. Not all of the material which was considered to be osteoporotic exhibited any outward sign that this was the case, confirming that, for accurate assessment of age-related changes within bone, examination of the internal bone structure is essential (Section 2.3.3).

A study of early medieval human skeletons (Wakely *et al.* 1989) identified age- and sex-dependent changes in the architecture of the trabecular bone in both the vertebral body and rib sections. However, single changes in the trabecular bone cannot be quantified or measured from a study involving single pictures. Accurate linear measurements cannot be made from a single two-dimensional micrograph, as it is not possible to obtain measurements in the third dimension (Howell *et al.* 1986). In order that a complex structure such as trabecular bone can be fully understood and quantified, measurements in three dimensions need to be obtained (Section 7.5.3). It is possible to obtain accurate linear measurements of structural elements from stereoscopic pair images derived from the SEM. However, compared with direct optical imaging, SEM is unnecessarily expensive, slow and cumbersome (Howell *et al.* 1986, Ross 1986).

5.6 Comparative Studies

Kneissel *et al.* (1994) sought to compare the results obtained with the various techniques discussed in this chapter. A sample of 18 individuals of mixed sex ranging in age from 20 - 60 years was taken from a 4000 BP collection. Trabecular numbers were counted using 3D stereoscopic photographs; bone mineral density was calculated using DEXA, (with water as a flesh substitute); radiographic bone mineral density was evaluated using standardised radiographic images; fractional bone volume (BV/TV) was calculated using backscattered electron images of the trabecular surface layer. The trabecular surface was then silver stained to allow the calculation of the trabecular bone pattern factor (TBPF).

Kneissel and co-workers (1994) used an X-ray method to calculate density. High quality digital or digitised radiographic images of the sample slices were analysed. Regions with line of sight pores were scaled to zero, whilst solid cortical areas were used to define a maximal intensity. It was then possible to index the fractional bone volume content averaged in the projection direction over the entire slice image and compare this with linear measurements obtained from the same specimen.

The sample numbers in this study were not large but the results were interesting. Poor correlation was found between the X-ray photon based methods such as DEXA and morphological methods (r= 0.34 DEXA and BV/TV, image analysis of trabecular bone). Consideration was given to possible diagenetic change of bone mineral after burial. Diagenetic changes in the sample material were characterised by fibre optic microscopy, laser scanning reflection confocal microscopy, and back scattered electron imaging using SEM. The fact that the material may have undergone diagenetic changes may have taken place was considered. It was found that the bone was greatly altered due to microbial and fungal tunnelling. No compositional analysis was undertaken though to find out what these changes might have been. This study was the first to highlight some of the pitfalls connected with methods which have been quite widely used on archaeological material.

5.7 Discussion and Conclusions

In none of these studies of cortical bone loss where data were available both from actual bone measurements and radiographic measurements were the two sets of results compared. Therefore it cannot be seen how closely they correlate. Nevertheless in all of the above studies cortical thickness was seen to decrease with age, and where comparisons were made between levels of loss between the sexes, females were observed to lose more bone than males. These trends reflect the broad patterns of bone loss with age seen in modern populations (Section 2.3.3). It must be remembered, however, that general bone loss with age (known as osteopenia) has been shown to be a normal part of the ageing process and such loss does not equate directly with osteoporosis (Jayasinghe 1991). Mays (1996) stated that study of cortical bone was very important for the understanding of osteoporosis because a high proportion of the skeleton comprises cortical bone. However, cortical bone thickness is no longer used clinically for the detection of bone loss, or for the identification of individuals who may be at risk of sustaining an osteoporotic fracture. It is now realised (Section 2.3.3) that such techniques do not provide a reliable indication of the likelihood of fracture. Overall, therefore, such techniques are not a good way to determine changes in bone with age and osteoporosis because they can only detect broad patterns of severe loss.

Trabecular bone is probably far more metabolically active than cortical bone(Dargent and Breart 1993), and therefore it is in this region that the effects of a disruption in bone remodelling will first be seen. As a result of the importance of trabecular structure, small losses have a significant impact on susceptibility to fracture (Section 2.3.3). Indeed, in modern populations, fractures are seen to occur most frequently in skeletal elements with a high trabecular bone content, such as the vertebral bodies, proximal femur and distal radius (Section 2.5). Therefore, for those specifically wishing to study osteoporosis as it is now defined clinically, data obtained from trabecular bone should provide more accurate information on bone loss, and the likelihood of the individual going on to suffer a fracture related to osteoporosis.

Problems associated with the analysis of archaeological bone in studies relating to pathology and mineral content have been discussed by previous workers (Bell 1990, Piepenbrink 1986). However, in the context of studies investigating age- and sex-related bone loss, no work has been carried out on the precise nature of possible diagenetic changes, and the exact way in which they may influence the results obtained from non-invasive investigative techniques. Whilst bones of the same type recovered in close proximity to each other might be expected to suffer from broadly similar post-burial changes, such changes have been shown to vary across sites and between individuals (Section 7.4). Reasons for these differences are not clear but factors such as the depth of burial in the ground may influence the way in which the bone is affected by groundwater movement. On a larger site, there may be significant differences in soil type and groundwater movement across the area, and Raptis (1992) himself states that "duration of burial and conditions of soil may have a common but unfortunately variable effect on post-mortem reduction of bone mineral content" (1992 p.122). It is not safe to make the assumption that "this process does not substantially interfere with the measurement of osteoporosis as all specimens of a certain site are subject to the same degree of demineralisation" (*ibid.* p.122). Whilst this statement may well hold true on some sites the processes involved are so variable this should never automatically be assumed to be the case (Section 7.4).

Archaeological bone sometimes feels light, and such bones are occasionally recorded as being osteoporotic (Scheuer and Black 1995). Whilst they may well be less dense than normal, the density of a bone is not sufficient evidence of osteoporosis. Factors such as root or animal damage may have removed trabecular bone, or alternatively bone may feel heavier due to the presence of soil within the bone. None of these is detectable from visual examination. The main drawbacks of the methods previously used are summarised below.

a) Radiographic Techniques. Those radiographic analyses which are currently readily available such as cortical thickness measurement and the Singh Index will only provide a crude indication of bone loss.
b) Non-Invasive Investigative Techniques. Density has been shown to be a poor indicator of fracture risk and all non-invasive techniques which calculate BMD can only reflect broad patterns of previous bone loss. Error may be introduced by applying techniques to archaeological bone that were originally developed for clinical use. There is also the possibility that diagenetic changes may lead to the production of erroneous results.
c) Analysis of Single Micrographs. A three-dimensional structure such as trabecular bone cannot be properly assessed in two dimensions, and analysis of simple micrographs does not allow correct measurements of structural elements.

The archaeological researcher should have a good grasp of bone biology and the mechanisms involved in the conditions of osteopenia and osteoporosis. Previous studies of age- and sex-related change in bone, and possible osteoporosis, have been further hampered by a lack of reference to current work undertaken on bone biology and osteoporosis, and in many instances it appears that the processes involved have not been fully understood. It is equally important to have a knowledge of the principles on which the techniques to be used are based and an awareness of how processes which have operated on material since deposition may influence the results obtained. This is clearly not the case in many of the examples quoted above.

In spite of these drawbacks, the majority of the studies discussed in this chapter seem to show the process of osteopenia, the gradual thinning of cortex and loss of bone with age reflecting findings from studies of modern material (Feik *et al.* 1996). This indicates that, as one would expect, the processes of bone biology have been proceeding for some considerable period of time in the way that is common today. What is needed is a larger study than that carried out by Kneissel *et al.* (1994) to see if the same results are obtained when comparisons between techniques are applied to a larger sample group. Her results suggested that patterns of bone loss were similar to those seen today, with greater levels of bone loss being observed in females between 40 and 60 years of age (Kneissel *et al.* 1994). However, the numbers in each age group were far too small for the results to have statistical significance. Correlations between the different methods were examined, but no base-line data was obtained on actual bone density, or quantification of structural integrity to allow these correlations to be seen.

The conclusion is inescapable: further work needs to be undertaken in order to establish what the relationship is between results produced from the various ways in which bone loss can be detected. Techniques such as the cortical index which calculate cortical bone loss should be included and the findings from such analysis compared to the results obtained from density and structural analysis. Stereometry, which would allow the measurement of trabecular bone in three dimensions to be made, should be used.

6. Materials and Background

6.1 Introduction

Sample material for the project was obtained from the sites of Redcross Way and Farringdon Street. The location of these sites within London is shown in Figure 6.1.1. This material was selected because both sites fitted neatly within the time period chosen for study. There are two other London sites of this period from which skeletal material has been recovered, St. Bride's crypt, and the crypt at Christ Church Spitalfields. The material from the crypt at St. Bride's cannot be removed from its storage area at the church and so could not be included in the present study. Experimental work of the type planned would be impossible with such restrictions in place. Permission to use a small sample from the well known collection from Christ Church Spitalfields was obtained but, in view of the rarity of the material and the extremely experimental nature of the work undertaken, some of which involved sectioning, this offer was not taken up. Another factor taken into consideration was the burial condition of the material. There would have been problems in using material from both St. Bride's and Spitalfields because the burials were placed in lead coffins. Material from St. Bride's has not been analysed for diagenetic changes, but it is known from radiological work undertaken on the material from Spitalfields that diagenetic changes had taken place and there had been an uptake of lead in some skeletons (Molleson *et al.* 1993). Such changes would have made the material unsuitable for use in a number of the experiments undertaken.

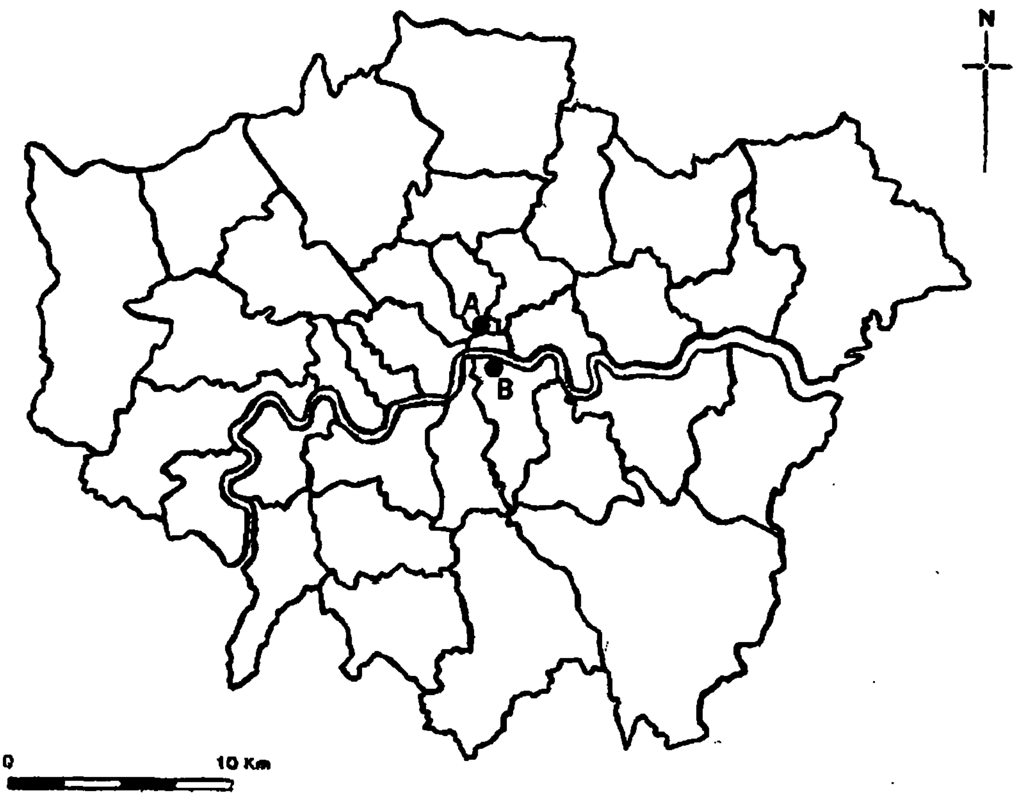


Figure 6.1.1 Map showing the location of (A) Farringdon Street and (B) Redcross Way within London., boroughs are indicated (after Miles 1993).

The material available from Redcross Way and Farringdon Street gave a large enough sample size for the present study. It was also possible to obtain permission from the Museum of London Archaeology Services to undertake extensive sectioning work on material from both sites.

6.1.1 The Redcross Way Cemetery

The first collection to be studied came from the burial ground at Redcross Way, in the parish of St Saviours, Southwark, London, which had been in use from AD 1700-1832. Excavation was carried out in 1992 by the Museum of London Archaeology Service and in total 149 individuals were recovered. Of these 46 were aged fifteen or older, the rest children and infants. The excavator considered that most of the skeletal material recovered came from the later period of the site. Excavation took place under rescue conditions as the site lay in the path of the Jubilee Line extension, and a sub-station was to be built on the site, requiring the ground level to be reduced by 1.5 m. Initially coffins were planned as they were excavated, but after just two days it became apparent that the time available for excavation would not allow such detailed recording to continue. The large number of burials, together with the limited amount of time, meant that the recording of burials using desirable archaeological methodology was not possible (Miles

1993). Therefore there is are data are available on the position within the ground of each skeleton.

It soon became clear, even from the limited area excavated, that it had been a burial ground used by the poorest members of society. Compared to other cemetery sites excavated around London, including known contemporary poor populations such as the lower church yard at St. Bride's (Farringdon Street), the form of burial suggested extreme poverty. The coffins used were of a very low standard. Most were of the cheapest wood, which had severely decayed, and "There was little evidence for decoration, even handles, the minimum that would be expected were scarce" (Miles 1992 p.22). Burials were packed tightly into large pits, and documentary evidence indicates that this was a regular practice in burial grounds for the poor in London during this period (Miles 1993).

This evidence of poverty is expected for the area in which the cemetery was located. Southwark has long had a reputation for being a run down and poor district. It was mentioned by Nash in *Pierce Penniless* (1595) as a place with an evil reputation (quoted in George 1925 p.82), and things had changed little by the time period covered in this study. Many sources gave colourful and graphic accounts of what the area and living conditions would have been like. One such account is attributed to a Dr Willan (quoted by George 1925 p.86).

> "It will scarcely appear credible, though it is precisely true, that persons of the lowest class do not put clean sheets on their beds but three times a year; that even where no sheets are used they never wash or scour their blankets or coverlets, nor renew them till they are no longer tenable".

His writings gave an impression of the unhygienic and extremely overcrowded conditions under which the majority of the population lived. Many families would have lived in a single room.

The period under study was a time of rapid growth. Finlay and Shearer (1986) estimated the population of London to be a little under half a million in AD 1701, and during the eighteenth century there was a doubling of this to 960,000, when the first census was taken in 1841. This rate of growth is remarkable when population information given by the Bills of Mortality is taken into consideration. It was only at the end of the eighteenth century that there were more baptisms than burials, so the population could only have continued to grow as a result of immigration. It is known that many immigrants settled in Southwark and adjoining parishes south of the river, and contemporary accounts indicate that there were large numbers of lodging houses in the area. Such accommodation was very cheap at only one or two pennies a night, but there could be as many as twenty people crammed into a room. Much of this type of accommodation was established in derelict or run down buildings, and it was not unknown for them to collapse. Examination of deeds and maps of the area for the period held at the Greater

London Record Office (GLRO) reveals that there were many tenement buildings clustered around small narrow streets and alleys. Engravings held by the GLRO depict densely packed houses in a very poor state of repair, around filthy streets (Figure 6.1.2 and Figure 6.1.3). Although the illustration of Mint Street (Figure 6.1.4) looks much cleaner, the houses are clearly poorly built.

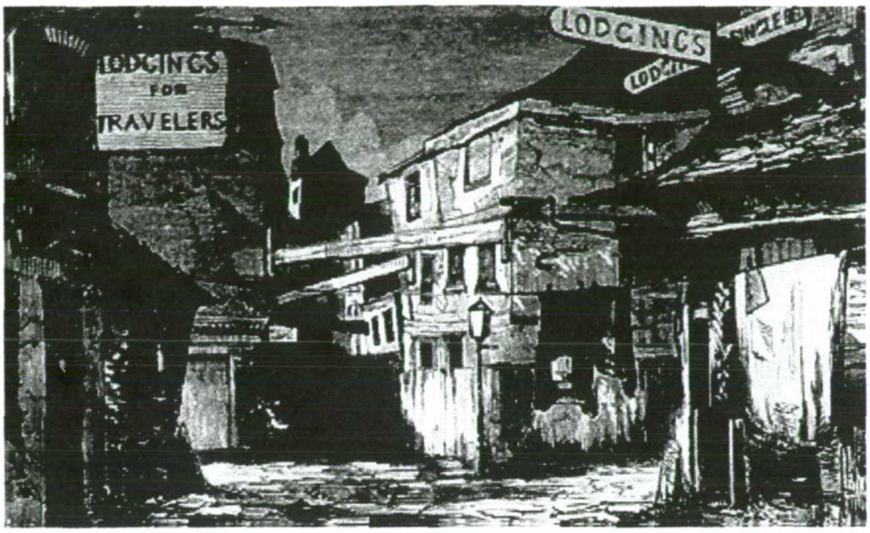


Figure 6.1.2 Duke Street, Southwark. Permission from the Greater London Record Office.

In much of the low standard housing of this period, disposal of waste from privies was a major health hazard. Inhabitants of the area were unwilling or unable to pay for proper disposal of sewage and, as a result, waste either ended up being dumped directly into the Thames, or a cesspool beneath the floor of the house. Records show that solid excrement was often heaped up to be sold. When "ripened" this substance was referred to as "dust" (Rudden 1985). Figure 6.1.4 shows "dust" piles heaped up in the background. It is unclear if this is the "dust" mentioned by Rudden (1985), or a by-product of the factory in the background.

Figure 6.1.3 Engraving of the back of Ewer Street and Gravel Lane, Southwark. Permission from the Greater London Record Office.

The water available to the inhabitants of South London during this period was also of a very low quality. Supplies of water for the area were extracted from the Thames between Vauxhall and Southwark which was extremely polluted (Landers 1993). The poor quality of drinking water was probably responsible for the transmission of a number of diseases amongst the inhabitants of Southwark.. Water was often mixed up with flour or breadcrumbs to form 'pap', that was commonly fed to babies during this period. Such feeding practices would have exposed the child to a wide range of infectious organisms contributing greatly to the high infant mortality. Another reason for the large number of infant burials may be that smaller coffins containing babies were used to pack and fill the top of burial pits. Excavation at Redcross Way was concentrated on the top layers of the site.

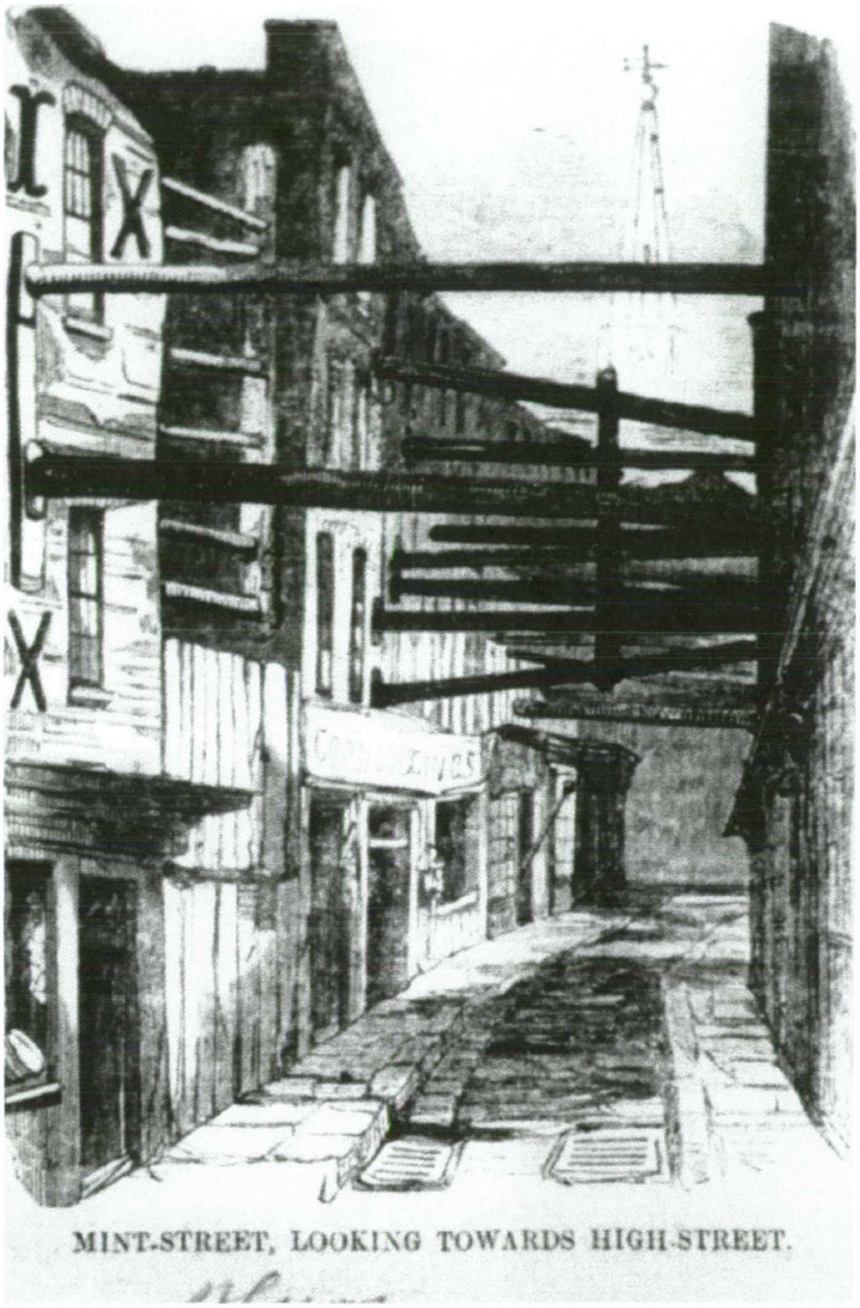


Figure 6.1.4 View down Mint Street, looking towards the High Street, Southwark. Permission given by the Greater London Record Office.

Levels of nutrition amongst this section of the population during this period would have been very low. A St. Saviour's parish committee meeting was called to discuss food allowances on 20th July 1795. The meeting was held because, at a previous meeting, it had been decided that rice and potatoes should be distributed in order to lessen the demand for bread, but this measure had failed, and it was resolved that any persons receiving allowances and then selling them on would not receive any more. Records for the parish also show that there were a large number of individuals in work houses, and the accounts show that large amounts of food and clothing had to be ordered for these people. Items listed regularly include; beer, flour, milk, beef and mutton, but there is no mention of fresh fruit and vegetables. Small amounts of port were also bought, presumably not for the residents. Burial registers show that throughout the period of study, around 25% of individuals buried at Redcross Way were recorded in the death register as having come from the work house.

Study of the human remains at Redcross Way points to high infant mortality due in part to the living conditions described. There were 44 adults and 102 individuals under the age of 18, the majority being less than two years of age. Although drastically different from the type of population distribution that would be found in a modern cemetery in the 'developed world', this would probably have been quite usual for the period under study, as a similar pattern is seen at Farringdon Street and parish records point to this having been the case. Infant mortality would have been extremely high due to infections which would be considered relatively minor today, and poor nutrition and housing would have aggravated the problem. Individuals who survived these childhood diseases would, however, have had a relatively long life expectancy (Section 6.3). The main dangers to life would have been accidents, for example at work, which today would require hospitalisation. It was noted in records relating to the parish that large numbers of males from this area were employed as manual workers and labourers, occupations which have an associated risk of accidents. The main threat to life for most females would have been parturition which has, until relatively recently, been extremely dangerous.

6.1.2 Farringdon Street Cemetery

The site at 75-82 Farringdon Street, London EC4 was excavated by the Museum of London Archaeology Service (MoLAS) between November 1991 and February 1992. The individuals buried at Farringdon Street are from broadly the same period as Redcross Way. Far more time was available and many more skeletons were excavated, with more detailed records than Redcross Way. Around five hundred individuals were exhumed, half of them adults. Of these only articulated burials (anatomically correctly placed when excavated) were recorded by MoLAS, as it was decided that this would be a large enough sample. The exact date at which the excavated area of the graveyard came into use is not clear, but pottery recovered indicated that many burials dated to AD 1770-1849, the last burials being in June 1849. Some individuals were recovered from a brick vault at the west end of the site which appears to have been in use between 1700 and 1800. As at Redcross Way, many burials were probably placed up to nine deep in large open pits.

The cemetery was an overflow cemetery for the St Bride's Parish. The area as a whole seems to have been slightly more prosperous than that served by the Redcross Way burial ground. Occupations listed in the parish records were of slightly higher status, with fewer labourers, and the area even had a small number of gentlemen and solicitors listed. Most coffins were severely decayed, but many were built of elm, with only a small number being constructed from cheaper softwoods such as pine, larch and spruce. There was also evidence of decoration in the form of painted or enamelled metal studs, and large number of coffin handles were found.

6.2 Methods: Age and Sex Determination of the Sample Material.

6.2.1 Introduction.

As the condition of osteoporosis is strongly related to the age and sex, it was felt important that the greatest possible care should be taken when assessment of the sample material was made. In this way the relationship of possible bone loss to age and sex can be observed. Although there are problems involved with epidemiological studies involving archaeological skeletal material (Waldron 1995), careful application of age bands will allow any broad changes in bone with age to be seen in the population.

6.2.2 Sexing

Most adult skeletons can be accurately sexed provided that they are reasonably complete, although there are variations in the level of sexual dimorphism seen within populations. In any collection of skeletal material there will always be some skeletons which display a combination of male and female characteristics making it impossible to assign a sex to them with confidence. The main elements of the skeleton used in this study were the skull, innominate and the sacrum. Where preservation of skeletal elements allowed, the procedure set down in *Standards For Data Collection From Human Skeletal Remains* (Buikstra and Ubelaker 1994) was followed. All skeletal material was allocated to one of five categories on the basis of scores awarded during the observation of sexually dimorphic features (Section 6.2.4.6).

6.2.3 Skull

The skull is one of the commonly used parts of the skeleton for sex determination. Males tend to have larger and more robust skulls than females (Keen 1950), but there is considerable variation in these characteristics between population groups. The regions of the skull scored during sexing are shown in Figure 6.2.1.

6.2.3.1 Supra-Orbital Ridge (glabella).

The cranium was viewed in *norma lateralis*, and the profile of the glabella compared with a series of five standard diagrams. Scores range from 1, in which there is little or no protrusion, through to 5 in which there is massive glabella prominence "forming a rounded, loaf-shaped projection that is frequently associated with well-developed supra-orbital ridges" (Buikstra and Ubelaker 1994 p.20).

6.2.3.2 Occipital Crest (nuchal crest)

The cranium was again viewed in *norma lateralis* and the area of muscle attachment was scored in relation to standard diagrams. Scores range from 1, where the surface of the bone is almost entirely smooth and there is no protrusion to be seen, to 5 when there is a massive nuchal crest. In such cases the bone is 'rugged' and there is a "well defined bony ledge or 'hook' " (*ibid.* p.19).

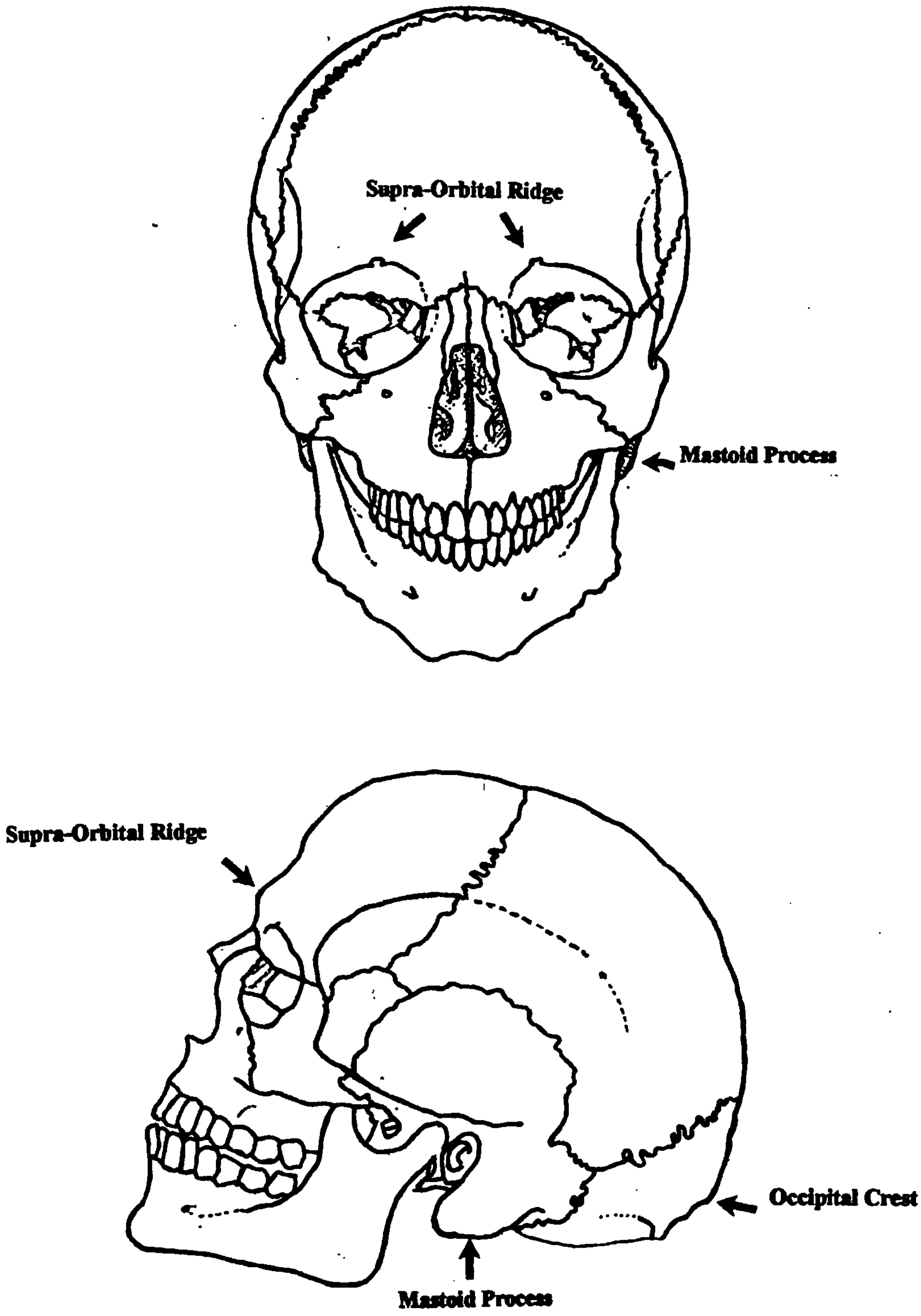


Figure 6.2.1 Regions of the skull from which sex was determined (after Bass 1992).

6.2.3.3 Mastoid Process

The dimensions of the mastoid were compared with other areas of the skull such as the temporal bone and zygomatic process to enable its size relative to other features to be assessed. The scheme used suggested that the most important point to consider when assigning a score is the volume. Scoring ranges from 1, in which the process is very small with only a slight projection below the lower edges of the external auditory meatus, to a score of 5 awarded when the process is extremely large and protrudes well below the base of the skull. It should also be several times larger both in length and width than the external auditory meatus.

In all of the scoring systems outlined above a score of 1 is considered very female, and 5 very male.

6.2.4 Innominate Bone (pelvis)

Provided it is well preserved, the innominate is considered to produce the most reliable estimates of sex (Phenice 1969, White and Folkens 1991). The full Phenice system was not used because the innominate was poorly preserved and very fragmentary in much of the sample material. Features which require small, detailed, specific observations to be made such as those made for the ventral arc and the ischiopubic ramus ridge, were not undertaken. Those which relied on broad overall shape of a larger area, such as the subpubic concavity and the greater sciatic notch, were found to be more useful. However, there were some samples to which even these broader changes could not be observed. Regions of the innominate used in the awarding of a score for sex are shown in Figure 6.2.2.

6.2.4.1 Pre-Auricular Sulcus

The sulcus is a depression located between the sciatic notch and the sacroiliac articulation, seen more commonly in females than males. When present, the smallest manifestation of this feature is scored 4. In such a case the preauricular sulcus is narrow (less than 0.5 cm), and seen as a shallow, smooth walled depression. In stage 3 it is usually well defined but still narrow, and less than 0.5 cm in depth. Stage 2 is seen as being wider and usually greater than 0.5 cm deep. In the most strongly developed cases where the pre-auricular sulcus is wide and is nearly always greater than 0.5 cm deep a score of 1 is awarded. Often the walls of the ridges are crossed by a series of bony ridges which "make the sulcus appear as if it is composed of lobes" (*ibid.* p.18). The sulcus is also longer than at the other stages and normally extends the entire length of the inferior auricular surface and may even undercut it. Absence of the feature should be recorded with zero.

6.2.4.2 Greater Sciatic Notch.

As a general rule, the greater sciatic notch appears broad in female skeletons and narrow in male skeletons. The situation can, however, be complicated by a number of factors, for example, the notch may narrow in females who are suffering from osteomalacia (*ibid.* p.18). The angle of the notch is scored from 1 to 5. A score of 1 is given to those with the widest angle and 5 given to the narrowest.

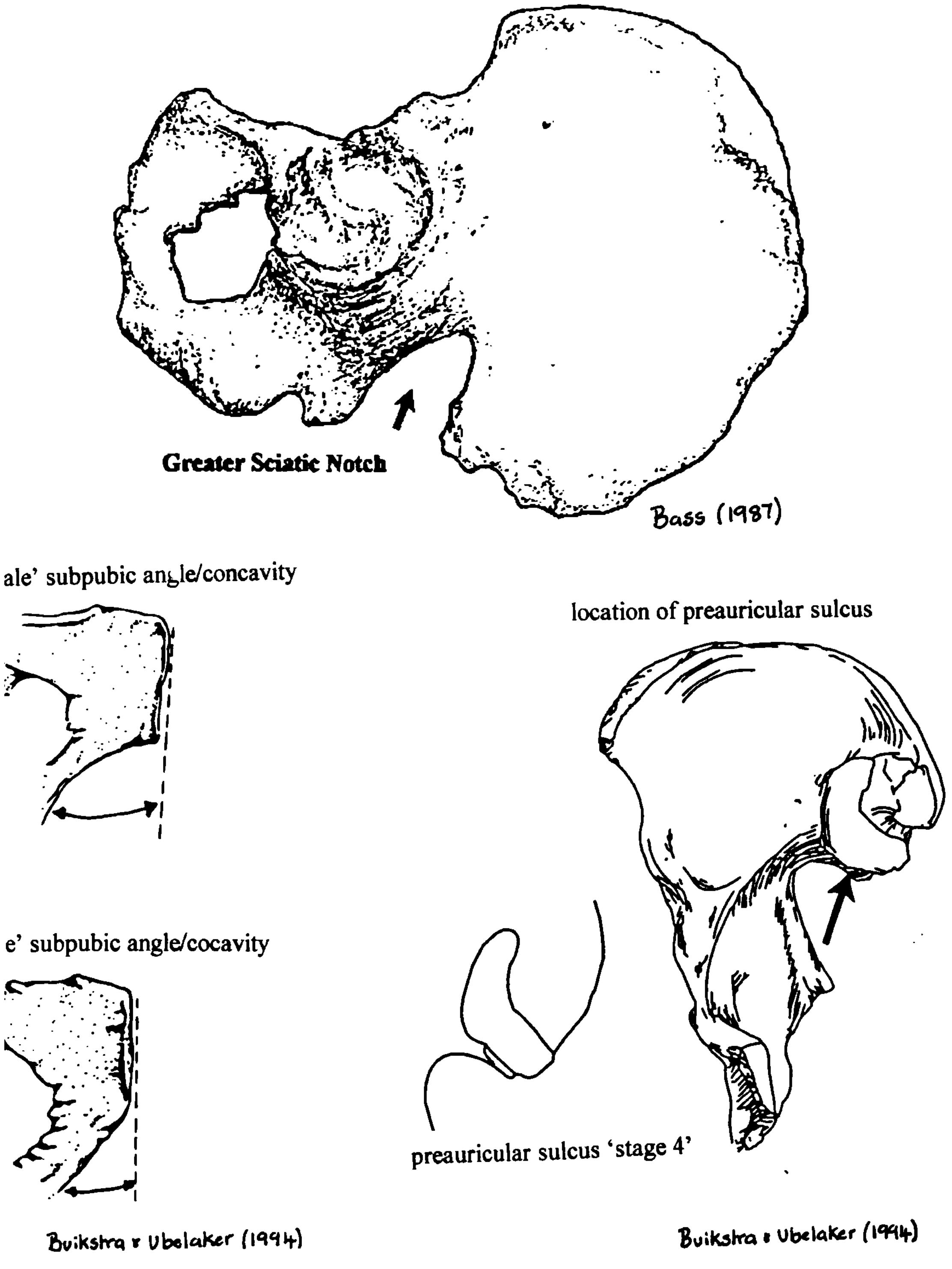


Figure 6.2.2 Regions of the innominate used for sex determination.

6.2.4.3 Subpubic Angle/Concavity.

In this technique the angle of slope from the pubic symphysis to the inferior ramus of the pubis and the ramus of ischium is assessed. In females the bone is normally concave in appearance, whereas males tend to exhibit a convex or flat surface in this region of bone. It is claimed that this method can identify sex in over 95% of cases (Phenice 1969).

6.2.4.4 Sacrum: Sacral Angle

Possible use of the sacrum in sex determination is not defined in *Standards* (1994). There is, however, a small section on the use of the sacrum in estimates of sex in Bass (1987, p.108). In general the sacrum is more curved in males than females. It has also been observed that the width of the proximal end of the sacral body and the ala are greater in males than females (Anderson 1962). The auricular surface often extends further down the side of the sacrum in males than females, often reaching the level of the third sacral foramen in males, whereas in females it usually only extends to the second. All these features mentioned should be considered together, as no single feature is likely to provide an accurate estimate of the sex of the individual.

6.2.4.5 Femoral Head Diameter

A check on the sex assigned to individuals from the site at Redcross Way was carried out, where possible, by measuring the diameter of the femoral head. Unfortunately in three cases the sex of the skeleton was ambiguous largely as a result of the poor state of preservation. However, the poor preservation meant it was not possible to obtain a measurement from the femoral head. Results were plotted on a graph (Figure 6.2.3) with different shapes for males and females. The two sexes were mainly grouped separately with a small amount of overlap. There was one well preserved individual from whom it had been possible to obtain bone samples for use in the present study, but who proved impossible to sex even with a combination of the methods described above. When the results for the femoral head diameter were plotted this individual was situated in the centre of the spread, meaning that it was still not possible to assign a definite sex.

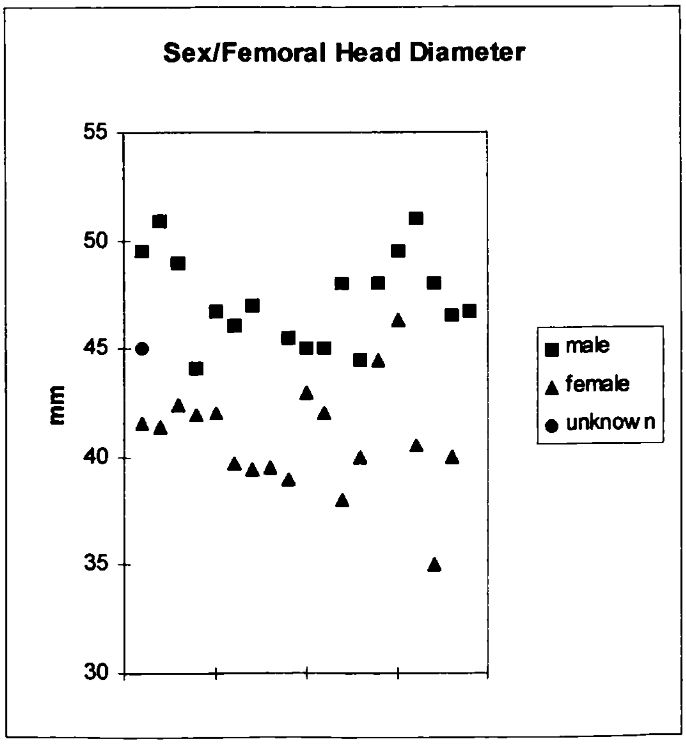


Figure 6.2.3 Femoral head diameter measurements obtained for individuals from Redcross Way. The x axis has no value and is the order in which the data were entered.

6.2.4.6 Sex Score

A score for sex was applied to each individual, from the combined scores obtained from each of the features examined. A score of 1 is applied to very female individuals, 2 is applied to individuals who display mainly female characteristics, 3 is applied to individuals who do not display either strongly male or female characteristics. Those with some male scores are scored as 4, (mainly male), and 5 is applied to samples with strongly male characteristics.

6.2.5 Ageing

As many techniques as possible were applied in order that confidence was increased. Ageing of archaeological material is more problematic than sexing, the older an individual becomes the harder it is accurately to assign an age. Only individuals aged fifteen years or older were to be used in the present study and it was decided that material should be grouped in the following age categories: 15-25, 26-35, 36-45, and 46+. Younger individuals were identified using ageing techniques such as ossification of bones and fusion of epiphyses (Bass 1987) and dental eruption patterns (Ubelaker 1987). For one of the bone loss assessment techniques used (trabecular length measurement, Section 7.5.3) it was decided to define an extra age category, 56+. In this instance age categories were then 46-55 and 56+. The criteria used to define these extra categories are explained in Section 6.2.8.

The features used to assign an age to determine which skeletons came from individuals under the age of 15, were:

a) pubic symphysis;
b) union of the epiphyses;
c) eruption of teeth;
d) tooth wear;
e) auricular surface;
f) rib phase.

Four individuals had carried out the initial assessment of age and sex on the material from Redcross way, so there was a possibility that inter-observer error had been introduced. To overcome this problem all individuals from the site were re-analysed by myself and assigned an age or phase. All work for each technique was done in a single session so that specimens could be directly compared and exactly the same criteria used. Some of the work was a repetition of earlier work, but re-analysing the sample material in this way increases confidence in the results obtained.

6.2.5.1 Rib Phase Analysis

This method was developed for use on the fourth rib (Iscan *et al.* 1984, 1985). Age estimates assigned to the scores are shown in Table 6.2.1. The region used for analysis is the sternal end, the area which forms the costochondral junction. Iscan *et al.* observed that throughout life the sternal end of the rib undergoes a series of changes. Several features are taken into consideration when deciding with which phase the features observed fit most closely. One of the main changes occurs at the slight pit or hollow present at the articular surface end of the rib; this is seen to increase in depth and width with age. The type of wall structure and surrounding rim of the pit also alters, with bony outgrowths and osteophytes developing from the edge of the rim. The overall condition of the bone around this region also undergoes age-related changes, with older individuals displaying greater bone porosity. Differences were observed between the rate and extent of changes in males and females so two sets of phases were developed. To help other workers to use this method, sets of casts were produced showing several typical rib ends displaying the features found at each stage in both males and females. There is also a detailed written description to assist the use of the casts and allow comparisons to be made.
(*Source of casts*; Iscan MY, Loth SR 1993. Casts of age phases from the sternal end of the rib for white males and females. France Casting, Bellvue, Co.)

There are, however, some problems with using this method on archaeological material. The technique was developed for the 4th rib, but it can be difficult to be sure which rib is the 4th in fragmentary archaeological material, as only the first and twelfth are distinctive. Every care was taken to select the fourth rib, or one close to it, but it could not be guaranteed that the fourth rib had been selected in each case. Use of a rib other than the fourth might introduce some error into ageing estimates, but it is unclear how large any errors might be. It was felt that changes in the adjacent ribs should be broadly similar. Another problem in applying this method is associated with fragmentation during burial. Although many of the changes relate to pit depth and width, the edges also undergo changes and, in older age phases, these edges become sharp and irregular with bony outgrowths. These features can be delicate and as a result may be lost in archaeological material. Forty six individuals from Redcross Way were observed, in one individual there were no ribs present and in five others they were so fragmentary as to be unusable. In the individuals to whom a sex could not be assigned, the method could not be applied, as differences between the sexes could have resulted in an inaccurate phase being assigned.

Male		Female	
Phase	Age	Phase	Age
0	16 and Younger	0	13 and Younger
1	17-19	1	14-15
2	20-23	2	16-19
3	24-28	3	20-24
4	26-32	4	24-32
5	33-42	5	33-46
6	43-55	6	43-58
7	54-64	7	59-71
8	65 and Older	8	70 and Older

Table 6.2.1 Rib Phases and the age range they equate to (Iscan and Loth 1993).

6.2.5.2 Ageing From The Pubic Symphysis

For some time, the pubic symphysis has been considered to be one of the most reliable areas for age determination in both men and women. The method is based on the fact that the symphyseal face of the pubic bone undergoes a regular metamorphosis from puberty onwards. The technique was initially developed by Todd (1920), described the main changes that occur. He divided the changes into ten phases from the age of 18 to 50+ and these changes form the basis of modern systems. In young people the symphyseal face is initially rugged and is traversed by horizontal ridges, and the edges of the symphysis are not clearly defined. As the individual ages the transverse ridges become infilled with bone, the edges of the region become more clearly defined, and ossific nodules also start to develop. By the time the individual reaches 35-40 years of age, the bone assumes a more granular texture, the rim becomes more marked and ossific disfigurement increase. Initial work by Todd has since been developed by a number of other researchers. It was first modified by Brooks (1955), then Mckern and Stewart (1957) published their three component age system. European research on the pubic symphysis resulted in the articles by Nemeskéri and co-workers (1960), and Acsadi and Nemeskéri (1970) in which a combined sex system of five pubic ages was proposed. Brooks and Suchey (1990) developed a system in which certain of Todd's ten phases were combined. Six phases were proposed and their accompanying statistics were developed and casts made available (Table 6.2.2). For the casts two bones were selected for each of the six phases, one showing an early pattern and one showing a later pattern. It was this set of casts and descriptions which I used during this study.

FEMALE				MALE			
PHASE	MEAN	SD	95% RANGE	PHASE	MEAN	SD	95% RANGE
I	19.4	2.6	15-24	I	18.5	2.1	15-23
II	25.0	4.9	19-40	II	23.4	3.6	19-34
III	30.7	8.1	21-53	III	28.7	6.5	21-46
IV	38.2	10.9	26-70	IV	35.2	9.4	23-57
V	48.1	14.6	25-83	V	45.6	10.4	27-66
VI	60.0	12.4	42-87	VI	61.2	12.2	34-86

Table 6.2.2 Phases in the pubic symphysis and the ages they relate to (Brooks and Suchey 1990) *(Casts available from;* Diane France, 2190 West Drake Road, Suite 259, Fort Collins, Colorado 80526).

Although it has been shown that this method of ageing can prove useful as a guide to ageing archaeological material, there are problems associated with its use. These largely stem from the shape and fragility of the region making the pubic symphysis very vulnerable to breakage. Of the individuals from Redcross Way, only ten had a pubic symphysis that was sufficiently intact to allow an estimation of age to be made. Preservation of this region was slightly better with the Farringdon Street material.

6.2.5.3 Auricular Surface

The technique of using the auricular surface of the ilium to assist in age estimation was developed by Lovejoy and co-workers (1985). It is based on bony changes of the auricular surface with age which appear to be relatively well defined and regular as the individual ages. Changes appear to be frequent enough to allow sixteen stages to be defined, from age 20 to 70. Slides depicting the characteristic stages accompanied by a written description are available to assist other workers in identification (available from the Department of Anthropology and Biology, Kent State University, Ohio). The large number of age categories, especially for older individuals, is perhaps optimistic on the part of the authors, but broad age categories can certainly be distinguished and the method allows seriation of the sample material.

The auricular surface starts with a billowing appearance (a series of smooth ridges). As the individual ages a slightly coarse granularity starts to be seen, and the billowing is gradually reduced with areas of coarse granularity becoming more prominent. By the time individuals are in their thirties, changes start to occur around the margins of the surface, and microporosity begins to appear. At forty years of age all evidence of the transverse arrangement apparent in youth is gone, marginal changes are more marked and areas of macroporosity emerge. With increasing age the changes around the margin become yet more marked with lipping developing, and the surface becomes increasingly irregular with small areas of dense bone and marked porosity. Lovejoy and co-worker's (1985) method is useful for archaeological material because the auricular surface has a very high survival rate. Only nine individuals from Redcross Way were lacking auricular surfaces. One other individual possessed auricular surfaces, but as there had been sacral fusion on both sides (the bones had broken apart during burial), it was felt it was not safe to assume that the usual pattern of changes seen would have been followed, and the individual was excluded.

6.2.5.4 Dental Wear

A number of systems have been devised whereby skeletons are aged according to the amount of dental attrition and abrasion they display, based on the fact that the teeth of an individual are gradually worn away during their lifetime, for example by abrasive food (Miles 1963, Zuhrt 1955). Such wear, which is normally found on the occlusal surfaces of the teeth, tended to be greater in populations living when there was less processed food in the diet. It was noted by Brothwell (1981) that rates of wear in British populations do not appear to have changed greatly between the Neolithic and Medieval period. A table of wear patterns which appears widely applicable and is easy to follow has been compiled (Brothwell 1981). However, this ageing system proved problematic on the material used in the present study (Section 6.4).

6.2.6 Presence of Ageing Features

The survival of different skeletal elements will determine in part how useful they are to the archaeologist. The survival rate of various skeletal elements at Redcross Way was noted during examination of the sample material. Details of survival of skeletal elements is given in Table 6.2.3.

Presence of Ageing Features	
The Auricular Surface was present in	80.4 %.
Rib Phase	80.4 %
Molars	56.5 %
Pubic Symphysis	17.4 %

Table 6.2.3 Percentage of the sample from Redcross Way from which bones were available.

In 8.7% of the individuals from Redcross Way none of the ageing features selected was present. 10.9% of the individuals only had one feature and 23.9% had two. However, 47.8% had three features which were well preserved. Only 8.7% had all four features which were well enough preserved to score.

6.2.7 Farringdon Street; Ageing and Sexing

Work of assigning an age and sex to each skeleton was carried out by Ms Conheeney, the Museum of London Archaeology Service (MoLAS) osteologist. In all cases as many indicators as possible were considered in order to gain the best age estimate.
Methods used:

Age of immature
Tooth development (figures in Ubelaker 1989)
Diaphyseal length (Ubelaker 1989, Sundick 1978)
Epiphyseal fusion (McMinn and Hutchins 1988, Salter 1984)

Age of mature
Changes to the pubic symphysis (Brooks and Suchey 1990, Gilbert and McKern 1973, McKern and Stewart 1957).
Fusion of cranial sutures (Meindl and Lovejoy 1985).
Changes to sternal rib ends (Iscan *et al.* 1984)

Sex estimation
The basic indicators used are those given in:
Bass (1987).
Brothwell (1981).
Phenice (1969).
The proforma used by Ms Conheeney includes features on the pelvis, skull, mandible, and several metric measurements such as femoral head diameter.

The age categories which were used by MoLAS were slightly different from those applied to individuals in the study carried out on Redcross Way. The main difference was that the two categories used for Redcross Way, 26-35 and 36-45, were grouped by MoLAS into the same age category, 26-45. This is done because it is felt that the additional information obtained by splitting this category would not add significantly to any of the archaeological interpretations required by MoLAS for the project. I assigned a score for age and sex to some of the skeletons from which sample material had been obtained from Farringdon Street without reference to data available from MoLAS, using the same ageing and sexing criteria outlined previously (Sections 6.2.2-6.2.4). In this way it was shown that age and sex scores applied to the material by myself and Ms Conheeney of Museum of London Archaeology Services were compatible. As many of the individuals as possible who had been placed in the category 26-45 were assigned to a more precise age category. The table (6.3.3) illustrates the results obtained.

6.2.8 Age Category 56+

The age categories 46-55 and 56+ were created in order that changes in bone with age could be observed in more detail. Only individuals with at least two well preserved ageing features were included in these categories. The criteria applied were:

46-55 years:
Rib phase 6 for males and females.
Pubic symphysis stage V.
Auricular surface age 46-50.

56 years +
Rib phase 8 for males and females.
Pubic symphysis stage VI.
Auricular surface age 65-70.

6.3 Results, Ageing and Sexing.

Details of the score awarded for sex and age to skeletal material from Redcross are given in Table 6.3.1 and Table 6.3.2.

Sex Estimation: Redcross Way

Skel. No.	Sex	Score	Skel. No.	Sex	Score
2	Male	4	99	Female	2
6	Male	4	100	Female	2
9	Male	4	101	Female	1
11	Male	4	114	Male	4
24	Female	2	116	Female	1
26	Female	2	118	Female	1
28	Female	2	119	Male	2
32	Female	2	120	Ambiguous	3
34	Ambiguous	3	122	Female	4
44	Ambiguous	3	136	Female	1
46	Male	4	137	Male	4
48	Female	2	140	Female	1
52	Female	4	150	Female	1
54	Male	4	155	Male	5
56	Female	1	157	Female	1
60	Male	5	159	Female	2
62	Male	4	161	Male	5
64	Female	2	165	Male	4
72	Female	2	167	Male	4
89	Female	2	169	Ambiguous	3
91	Male	4	171	Male	4
92	Ambiguous	3	175	Male	4
96	Female	1	no number	Male	5

Table 6.3.1 Scores for sex awarded to adult skeletons available from Redcross Way.

sex score
1 = definitely female.
2 = probably female.
3 = ambiguous.
4 = probably male.
5 = definitely male.

Age Estimation: Redcross Way					
Skeleton	**Auricular**	**Tooth Wear**	**Pubic**	**Rib Phase**	**Age**
no number	70	X	X	7	46+
2	X	1 / 3+	X	2	15-26
6	50	4+ / 5+	X	6	46+
9	35	X	X	X	36-46
11	46	X	X	6	46+
24	36	3 / 4	4	5	26-35
26	50	2 / 4	X	8	46+
28	44	X	X	6	46+
32	50	5 / 5+	X	6	46+
34	X	X	X	X	adult
44	47	X	X	X	46+
46	X	1	1	0	15-26
48	65	X	X	7	46+
52	70	5+	X	8	46+
54	33	1 / 3+	X	3	26-35
56	44	1 / 3+	X	6	36-45
60	50	5+ / 5	5	8	46+
62	65	X	5	5	46+
64	50	2 / 2+	X	5	46+
72	70	X	X	7	46+
89	25	2+	X	X	26-35
91	70	4+ / 5+	X	8	46+
92	X	X	X	X	adult
96	28	2+ / 4+	X	4	26-35
99	28	X	X	4	26-35
100	50	2+ /4+	X	6	46+
101	44	2 / 3	X	5	36-45
114	65	X	X	7	46+
116	44	1 / 2	X	6	36-45
118	46	2 / 5	5	6	36-45
119	X	4+ / 5	X	X	46+
120	X	X	X	X	adult
122	X	X	X	8	46+
136	25	2 / 2+	X	3	15-25
137	35	X	5	6	26-35
140	24	3 / 4+	X	X	26-35
150	70	X	X	7	46+
155	46	X	4	6	36-45
157	70	2 / 5+	6	7	46+
159	X	X	X	8	46+
161	65	3 / 5+	X	7	46+
165	X	3 / 4+	4	6	36-45
167	28	2+ / 4	X	5	26-35
169	X	X	X	X	adult
171	65	2 / 4	X	7	46+
175	50	4 / 4+	X	7	46+

Table 6.3.2 Comparison of the age or phase awarded under each of the systems used. X indicates that the skeletal area required for the technique was unusable. The age in the present study refers to the age awarded during the initial assessment of material by Megan Brickley, Raoul Bull, Julia Heffernan and Hilary Stainer.

Comparisons of scores awarded for age and sex in the present study and MoLAS are provided in Table 6.3.3. This was done to ensure that age and sex data provided by MoLAS could be used.

MoLAS				MBB		
Skel no.	Sex	Score	Age	Sex	Score	Age
1116	male	2	26-45	male	1	26-45
1119	not listed			female	4	36-45
1123	female	5	26-45	female	5	36-45
1174	female	4	46+	female	4	46+ u
1200	male	2	26-45	male	2	36-45
1209	female	5	adult	female	4	46+ x
1247	male	2	26-45	male	1	26-35
1251	male	1	26-45	male	1	36-45
1278	female	4	26-45	female	4	26-35
1281	female	5	26-45	female	5	36-45
1291	male	2	26-45	male	2	36-45
1292	male	2	adult	male	2	36-45
1298	male	1	adult	male	1	36-45
1312	male	1	46+	male	1	46+
1330	male	2	adult	male	2	26-35
1343	female	5	46+	female	5	46+ l
1350	female	4	46+	female	5	46+ u
1366	female	4	adult	female	5	36-45
1379	not listed			female	4	36-45
1390	male	2	adult	male	2	36-45
1408	male	1	26-45	male	1	36-45
1409	female	5	46+	female	5	46+ u
1415	male	1	adult	male	1	36-45
1420	male	1	26-45	male	2	26-35
1428	female	4	26-45	female	4	36-45
1441	female	5	46+	female	5	46+
1449	male	1	26-45	male	1	36-45
1515	male	1	26-45	male	2	36-45
1519	male	2	26-45	male	1	26-35
1546	not listed			female	4	46+ l
1549	male	1	26-45	male	2	36-45
1578	male	1	26-45	male	2	26-35
1580	male	2	26-45	male	2	26-35
1586	female	5	26-45	female	5	36-45
1599	male	1	26-45	male	2	26-35
1606	male	1	46+	male	1	46+ l
1608	male	1	26-45	male	2	46+ l
1610	female	5	26-45	female	5	36-45
1611	female	5	26-45	female	2	36-45
1621	male	1	adult	male	2	adult

Continued overleaf

MoLAS				MBB		
1649	female	5	26-45	female	5	36-45
1653	female	5	26-45	female	5	26-35
1671	female	5	46+	female	5	46+
1673	male	1	26-45	male	2	36-45
1685	male	1	46+	male	1	46+ x
1691	female	4	46+	female	4	46+ u
1695	male	1	46+	male	1	46+ u
1707	female	4	26-45	female	4	46+ x
1709	female	5	26-45	female	5	36-45
1727	male	1	26-45	male	1	26-35
1755	female	5	26-45	female	5	26-35
1767	male	1	26-45	male	1	26-35
1781	female	5	26-45	female	5	26-35
1787	female	5	adult	female	5	adult
1791	unknown	3	6-12	unknown	3	6-12
1793	female	5	26-45	female	5	26-35
1795	male	2	46+	male	2	46+ u
1809	female	5	26-45	female	5	26-35
1845	male	2	26-45	male	2	26-35
1853	male	2	adult	male	2	36-45
1860	male	1	26-45	male	1	26-35
1862	male	1	46+	male	1	46+ l
1879	male	1	26-45	male	1	36-45
1891	female	5	adult	female	4	adult
1893	male		26-45	male	2	26-35
1897	unknown	3	26-45	female	4	36-45
1899	female	5	26-45	female	5	26-35
1903	unknown	3	26-45	female	4	26-35
1913	female	4	46+	female	4	46+ u
1919	unknown	3	26-45	adult	3	36-45
1925	male	1	26-45	male	2	36-45
1930	male	1	26-45	male	1	36-45
1934	female	5	26-45	female	5	26-35
1938	not listed			female	4	26-35
1942	male	1	adult	male	1	46+ u
1952	female	4	adult	female	4	26-35
1954	female	5	46+	female	5	46+ u
1957	male	1	26-45	male	2	26-35
1972	male	1	26-45	male	2	26-35
1990	female	4	adult	female	4	26-35
1991	male	1	46+	male	1	46+ l
1997	male	1	26-45	male	2	46+ x
2001	male	1	46+	male	2	46+ u
2009	unknown	3	adult	unknown	3	adult

Continued overleaf

MoLAS				MBB		
2011	male	1	26-45	male	2	36-45
2043	male	1	26-45	male	1	36-45
2053	male	2	adult	male	2	36-45
2065	unknown	3	adult	unknown	3	adult
2073	not listed			female	5	26-35
2077	male	1	46+	male	1	46+ l
2081	male	1	26-45	male	2	36-45
2105	female	5	46+	female	5	46+ u
2109	male	1	46+	male	1	46+ l
2116	female	5	26-45	female	5	36-45
2122	female	5	no data	female	5	36-45
2124	male	1	46+	male	1	46+
2126	male	2	26-45	male	2	36-45
2130	male	2	26-45	male	2	36-45
2132	female	5	46+	female	5	46+
2134	female	4	26-45	female	4	26-35
2140	male	1	26-45	male	2	26-35
2158	female	4	46+	female	4	46+
2161	female	5	26-45	female	4	26-35
2164	male	1	26-45	male	2	36-45
2165	male	1	26-45	male	1	26-35
2175	unknown	3	26-45	unknown	3	26-35
2185	male	1	adult	male	2	46+
2193	male	1	46+	male	1	46+
2195	male	1	46+	male	1	46+ u
2199	female	5	26-45	female	4	26-35
2205	male	1	26-45	male	1	36-45
2223	female	5	26-45	female	5	26-35
2233	female	5	46+	female	5	46+ l
2263	male	2	46+	male	2	46+ l
2269	male	1	46+	male	1	46+ u
2288	male	2	46+	male	2	46+
2298	not listed			male	2	36-45
2302	female	5	26-45	female	5	36-45
2332	male	2	26-45	male	2	46+ l
2340	male	1	26-45	male	2	36-45
2383	female	5	26-45	female	5	26-35

Table 6.3.3 Comparison of the age and sex scores awarded in the present study (MBB) and by the MoLAS osteologist. l=46+, u=56+.

In the majority of cases the scores awarded for age and sex in the present study and by Jan Conheeney were very similar. Any differences seen tend to be in the degree of certainty with which a sex was assigned.

6.3.1 Comparison of Age Estimates to Evidence from Documentary Sources

Three documentary sources were consulted to obtain comparison with estimates made through skeletal analysis: records compiled from St. Bride's crypt registers and coffin plates, Redcross Way death registers (GLRO x70/1) and Farringdon Street death registers (Guildhall London Ms 6543/1-3 and 6551/1-3). For Redcross Way, death registers from the years 1789 - 1800 were consulted, and for Farringdon Street 1739-1825. It is possible that the exact age of some of the individuals recorded in the death registers was not known and the age recorded was an estimate. However, the inaccuracies introduced through such practices are likely to be small compared with the problems involved in age estimation of archaeological skeletal material. All individuals below the age of 15 were excluded from the tables, as only adults over this age category were to be examined in the present study. Details of individuals listed in the records were grouped in the same age categories as the archaeological material.

In women, osteoporosis-related fractures start to become common after the age of fifty: 64% of the women from St. Bride's and 59.6% of the women from Redcross Way were fifty years or older. By the age of seventy there is an even greater personal risk of sustaining an osteoporosis-related fracture: women over the age of 70 made up 26.5% of the female population and men 13.3%. The figures were similar at St. Bride's where women over the age of 70 made up 21% of the buried population and men 18.2%. The pattern observed from records relating to Farringdon Street show a comparable pattern. Females over the age of fifty years make up 55.6% of the female population and those over the age of seventy were 18%. Males over the age of fifty years made up 50% of the male population, and those over seventy 14.5% of the population. Thus it is clear that during the period covered by this study there was a significant proportion of the adult population who reached an age at which today they could be considered a risk of sustaining an osteoporosis-related fracture.

The proportion of individuals in each age category from the death registers was compared to the results obtained from the ageing techniques applied to individuals from Redcross Way and Farringdon Street Table 6.3.4 - Table 6.3.8. For both sites only individuals for which there was an age and sex available were included in the calculations.

Redcross Way - Age Estimates (present study).			
Age Category	% of total,	Male,	Female,
46+	56.1 %	57.9%	54.5%
36-45	17.1 %	15.8%	18.2%
26-35	19.5 %	15.8%	22.7%
15-25	7.3 %	10.5%	4.6%

Table 6.3.4 The percentage of individuals in each category calculated during the present study from age estimates for Redcross Way sample material.

Redcross Way - Death Registers			
Age Category	% of total,	Male,	Female
46+	59 %	53.8%	62.9%
36-45	22 %	22.4%	22.5%
26-35	11 %	15.4%	6.0%
15-25	8 %	8.4%	8.5%

Table 6.3.5 The percentage of individuals in each category calculated from death registers available for Redcross Way.

St. Bride's - Death Registers			
Age Category	% of total,	Male	Female
46+	66.8 %	66.4%	67.4%
36-45	11.2 %	9.1%	13.4%
26-35	12 %	11.8%	11.6%
15-25	10 %	12.7%	7.4%

Table 6.3.6 The percentage of individuals in each category calculated from records available for St. Bride's

Farringdon Street Death Registers			
Age Category	% of total	Male	Female
46+	58.3%	54.9%	61.6%
36-45	16.9%	17.1%	16.8%
26-35	14.2%	16.1%	12.3%
15-25	10.5%	11.9%	9.3%

Table 6.3.7 The percentage of individuals in each category calculated from death registers available for Farringdon Street.

Farringdon Street Excavated Sample			
Age Category	% of total	Male	Female
46+	41.5%	40.2%	40.7%
26-45	56.5%	56.1%	56.3%
17-25	2%	3%	3%

Table 6.3.8 The percentage of individuals in each category calculated from the site archive held by MoLAS. Only individuals for whom both age and sex were known were included.

Results compiled from the Farringdon Street site archive do not match the death register data well. This may be because many skeletons were excluded from the calculations in the table as either age or sex is recorded as indeterminate. Another factor which may have influenced this result is that only articulated skeletons were excavated. The results produced from examination of archaeological material from Redcross Way broadly match those produced by the death registers, when both sexes are considered together. In each case, the largest age category is > 46+ years and the lowest is the age category 15-25 years. The results from the death register at Redcross Way and Farringdon Street match the results of ageing for the present study more closely than the St. Bride's material. This is only to be expected as the St. Bride's material comes from a different socio-economic group. Records available show that the individuals buried in the crypt were wealthy, often with high ranking positions within society. At Redcross Way it appears age at death was not automatically recorded in the death registers, making a study of the population from this source difficult. This may account for the slight differences seen between estimates calculated from the present and the information derived from the death registers. The number of individuals for whom age is given in the register varies through time:

1790	13.8%
1791	16.3%
1792	20.9%
1796	25.9%
1800	41.1%
1805	63.4%
1810	53.4%

By 1832 over 95% of the individuals recorded were given an age at death. This seems to have been the case from at least 1732 onwards for the Farringdon Street material, and may reflect the slightly better social status of individuals using this burial ground. At Redcross Way there are quite a number of instances in which the person buried is simply referred to as 'man found in market place' or 'infant found in .... Street'.

The number of skeletons included in calculation of age at death from Redcross Way skeletal material is very small (only 45). From such a small number it is difficult to get an accurate assessment of the pattern within the wider population. The total population scores for the percentage of both males and females in each age category may be a more reliable way of examining population trends. Such a figure gives an indication of broad trends, which may be more useful given all the inaccuracies inherent in this type of study. The mixed sex (% of total) are the most consistent results produced, with those from Farringdon Street and Redcross Way being very similar.

In the statistical analysis (Sections 8, 9 and 10) age is in some cases correlated with, or plotted against results from various of the investigative techniques. In such cases the age entered for the category 15-25 years is 20, 26-35 years is 30, 36-45 years is 40, 46-55 or 46+ years 50 and 56+ years 60. The actual mean and mode for each of these age categories calculated from the death registers for Redcross Way and Farringdon Street are given below.

Males			Females		
Age Category	**Mean Age**	**Mode Age**	**Age Category**	**Mean Age**	**Mode Age**
15-25 years	21.2	23	15-25 years	21.0	24
26-35 years	31.1	30	26-35 years	31	30
36-45 years	40.2	36	36-45 years	41.2	40
46-55 years	51	53	46-55 years	51	50
56+ years	68	60	56+ years	67	60

Table 6.3.9 Mean and mode ages calculated from the death registers from Farringdon Street, for males and females.

Males			Females		
Age Category	**Mean Age**	**Mode Age**	**Age Category**	**Mean Age**	**Mode Age**
15-25 years	19.2	21	15-25 years	21	18
26-35 years	30.4	29	26-35 years	30	30
36-45 years	40.4	40	36-45 years	40.5	40
46-55 years	51	45	46-55 years	51	48
56+ years	67.2	60	56+ years	70	70

Table 6.3.10 Mean and mode ages calculated from the death registers from Redcross Way, for males and females.

Table 6.3.9 and Table 6.3.10 show that the figure age 20, 30, 40 were reasonable ages to enter for plots and correlations where a figure is needed. There is, however, a very large range of ages in the categories 46+ and 56+. There is nothing that can be done about the large spread of ages which must be placed in the oldest age category. It is difficult to age archaeological material over 50 years of age.

6.3.2 Menopause

The onset of the menopause has an important role to play in the possible development of osteoporosis (Section 3.3.2) and its timing is therefore an important factor. It could reasonably be expected that such a biological event would not have changed significantly through historical time. Research indicates that menopause at approximately fifty years of age seems to be a fixed point in our maximum lifespan (Pavelka and Fedigan 1991) that does not appear to vary cross-culturally. A number of reports confirm that from the 1850s to the present, the age of menopause remained constant at approximately fifty years (McKinlay *et al.* 1972). What little evidence there is in historical literature about the menopause would appear to indicate that there has been no significant change in the age at which it occurs for at least several thousand years.

Today the average age for onset appears to be around 50. Classical sources, for example Aristotle (*Historia Animalium*), place it between 40-50, with a maximum of 60 years of age (Amundsen and Diers 1970).

6.4 Discussion

Evidence from the death registers that the age category 46+ covers a large range of ages, with many individuals being considerably older than the lower limit, indicates that analysis of the results will be difficult. As many of the changes related to osteoporosis occur in this age category it will only be possible to discern broad age-related trends. For most individuals all the techniques used for age estimation yielded a similar result. However, in some individuals there was not a tight agreement between the different methods. It was decided that in such cases the individual should be assigned to the age category which most techniques agreed upon. For example, Redcross Way no. 62 produced an age of 65 from auricular surface ageing, the pubic symphysis produced a score of V, (mean age for this score is 48.1 years but there is a range of 25-83 years), and rib phase analysis produced a possible age range of 33-42. The original age assigned to the individual during preliminary investigations was 46 +. It was decided that the individual probably fell into the age category 46+. Slight differences in results are an indication that in some individuals different areas of skeletons are 'ageing' at different rates. Specific lifestyle factors or stresses experienced by the individual may be responsible for this.

In the present study difficulty was experienced when applying traditional tooth wear patterns to the collections from Redcross Way and Farringdon Street. A detailed study was made of the tooth wear in the material from Redcross Way. In only 13 % of cases did the score for dental wear agree with other ages obtained. In 20.5 % of the individuals examined the possible score for the individual was extremely wide but the age assigned through other techniques did fall within the range of scores possible. However, in 11.4 % of individuals examined, the dental wear score obtained was totally different to that obtained through other ageing techniques. This could be due to dietary differences between this population and the ones upon which tables are based. Dietary factors may account for the high rates of caries and periodontal disease observed in London populations during the period covered by this study (1700-1850). Poor dental health within the population leading to tooth loss and caries meant that many teeth were missing or too damaged to be scored. Walker (1996), in a study of tooth wear using sample material from St. Bride's (a London population of similar date) also concluded that it was of little use as an ageing technique. Tooth wear was not used by Ms Conheeney of MoLAS on the material from Farringdon Street as it was felt that it could not be relied upon in this collection because wear tended to be light relative to apparent age (Conheeney *Pers. Com.*). As can be seen in Table 6.3.2, the dentition does not appear to be a reliable age indicator for London populations of the period covered by this study.

The fact that dental attrition was shown to be a poor indicator of age within London populations of this period was regrettable, as this technique depends on wear throughout the lifetime of the individual rather than biological ageing of the skeleton. The possibility of changes related to the condition under study influencing the age score awarded had to be considered. Osteoporosis is a condition which involves deterioration of bone and all the ageing techniques applied to the sample material involved bony changes with age. As mentioned in Section 2.3.3 the condition predominantly affects the structural integrity of trabecular bone and thinning of the cortex, which cannot be observed from the exterior of the bone. None of the ageing techniques applied involved observation of trabecular bone, and from what is known of the condition it was felt that development of osteopenia and in some cases osteoporosis would not influence the assessment of age.

It is often assumed by the general population, and even some archaeologists, that past populations did not have a life expectancy long enough for them to be at risk from a condition such as osteoporosis (Dequeker *et al.* 1997, Foldes *et al.* 1995). Research on human remains seems to indicate that the minimum expected life span is a species specific characteristic (Cutler 1975, 1978, Sacher 1975, 1976). As much as 80% of the variation in the lifespans of mammalian species may be due to factors such as body size, brain size, metabolism and body temperature. On the basis of such calculations the maximum lifespan of *H.sapiens* fits well with what would be expected.

Although no firm evidence exists it is probable that there has been very little if any change in our maximum lifespan for a considerable period of time. Evidence gathered from documentary sources shows that there would certainly have been no difference in the maximum life expectancy between the period covered by this study and the present day, with a number of individuals from all sites recorded as in their nineties. What has changed through time is population demographics. There has been a steady and significant increase in the number of individuals who attain the maximum age. Such demographic changes were discussed by Gray (1976). He claims that the reason for increases in the mean female life expectancy at birth during the 20th century is primarily due a huge reduction in infant mortality. Such a reduction is not due to biological changes within the species, but to external factors such as healthier, improved sanitation and better nutrition. Examination of London death registers and crypt populations for the period under study seems to support this view. There was indeed very high infant mortality but, if childhood was survived, there was a good chance of living to an age at which there was a risk of sustaining an osteoporosis-related fracture.

7. Methods

7.1 Introduction

There are two approaches for assessing bone loss with age. These are the study of changes in bone density or mass, and the analysis of structural change, due to cortical thinning and changes within the trabecular region. Before any work can be undertaken on the assessment of bone loss and the prevalence of osteoporosis in archaeological material, the methods have to be carefully considered. In the present study a range of different methods for determining bone loss with ageing and possible osteoporosis were tested on the material from Redcross Way and Farringdon Street. From this work some conclusions can be drawn as to which techniques are suitable for wider application to archaeological bone. The range of skeletal areas used will enable the relative usefulness and problems associated with each bone to be assessed. Relationships between bone loss at different areas within an individual will also be examined. A number of radiological methods were used to determine the bone density, cortical bone loss and trabecular structure.

The techniques chosen to assess changes in density were:

a) calculation of density from weight and volume of bone slices (base-line density);
b) optical densitometry - (whole bone);
c) optical densitometry - (trabecular region only);
d) Dual Energy X-ray Absorptiometry (DEXA);
e) Low Angle X-ray Scattering (LAXS).

The last four of these techniques are radiological techniques. The results of the application of these techniques are given in Chapter 8.

Methods applied to look at trabecular structural loss were:

a) Singh index (radiological technique);
b) stereometry.

The results of the application of these techniques are given in Chapter 9.

The methods chosen to assess cortical bone loss were:

a) calculation of cortical index (radiological technique);
b) actual cortical thickness measurements;
c) calculation of cortical area.

The results of the application of these techniques are given in Chapter 10.

Comparisons were made between results obtained from the various investigative methods applied (Chapters 8, 9 and 10). In order to ensure that in all the methods tested exactly the same region was examined, the region of interest was marked by a pencil line on the whole bones before investigations began. This approach ensured that the comparison between the techniques was not affected by any heterogeneity within the bone.

7.1.1 Skeletal Regions From Which Samples Were Taken - Reasons for Choice

Four skeletal regions were selected for analysis from Redcross Way, these are shown in Figure 7.1.1. The regions of the skeleton chosen for examination were:

a) the right femur;
b) the left radius;
c) the fourth lumbar vertebra;
d) the iliac crest.

The first three areas of the skeleton, (femur, radius, 4th lumbar vertebra), were selected for study in this project because they are areas of the skeleton with a high trabecular bone content and are therefore common sites of fractures in living individuals (Section 2.5). The side of the body from which the femora and radii were selected was dictated by the numbers of well preserved skeletal elements available from each side. These skeletal sites can therefore provide a great deal of information on bone loss in the historical period under study. As there has been a great deal of clinical research on them published, the results from the present study can be put in context.

The region of the femur chosen for analysis was the femoral neck. This is a site of osteoporosis-related fractures in the modern population (Section 2.5.1); as a result, many previous studies have focused on this region. Archaeological studies include Bennike and Bohr (1990), Lees *et al.* (1993), and Kneissel *et al.* (1994). Studies of modern material are extensive, including Riggs *et al.* (1982), and Mautalen *et al.*(1990). The number of bone elements from each skeleton which were available from each skeleton at Redcross way is shown in Table 7.1.1.

The region of interest on the radius is the distal end immediately above the ulnar notch. Archaeological studies of this area include Perzigian (1973 a and b), Mazess (1982) and Horsman and Leach (1974). Work on modern material has been extensive and includes Riggs *et al.* (1981) and Mautalen *et al.*(1990).

All the lumbar vertebrae have been extensively studied, but in some cases the fourth lumbar vertebra has been singled out. The fourth lumbar vertebra does not appear to give better information than the others, but once it had been selected for use in some studies, other researchers who were only able to select one vertebra also chose it so that results from different studies could be compared. Archaeological studies of the lumbar spine include those by Wakely *et al.* (1989), and Roberts and Wakely (1992). A study of archaeological material by Kneissel *et al.* (1994) concentrated on the fourth lumbar vertebra. Clinical studies have been extensive and include Riggs *et al.* (1981), Mautalen *et al.* (1990), and Wright *et al.* (1990) and a study by Jayasinghe *et al.* (1994) focused on changes within this bone. While the sagittal section is commonly selected as the preferred plane of orientation of analysis in present day autopsy material, a coronal section through the midpoint of the vertebral body was selected. The sagittal section is dominated by an area of little bone due to the vasculature (Jayasinghe *et al.* 1994). A coronal section has less vascularity and a far greater area.

The iliac crest was selected for study because it is from this site that bone biopsies are taken (Rao 1983). Bone samples have been removed from this region from living individuals for over thirty years (Boyce 1989). Iliac crest biopsies allow the study of bone loss with ageing and bone pathologies, and it is possible to employ tetracycline labelling in *vivo* to allow bone processes to be better understood. Repeat biopsies can be taken on the same individual, allowing a pattern through time to be built up. Studies involving the iliac crest include Parfitt *et al.* (1983), Wright (1990), and Mellish *et al.* (1991). The area of biopsy has been studied in archaeological bone material (Foldes *et al.* 1995, Gozález-Reimers and Arnay-de-la-Rosa 1992).

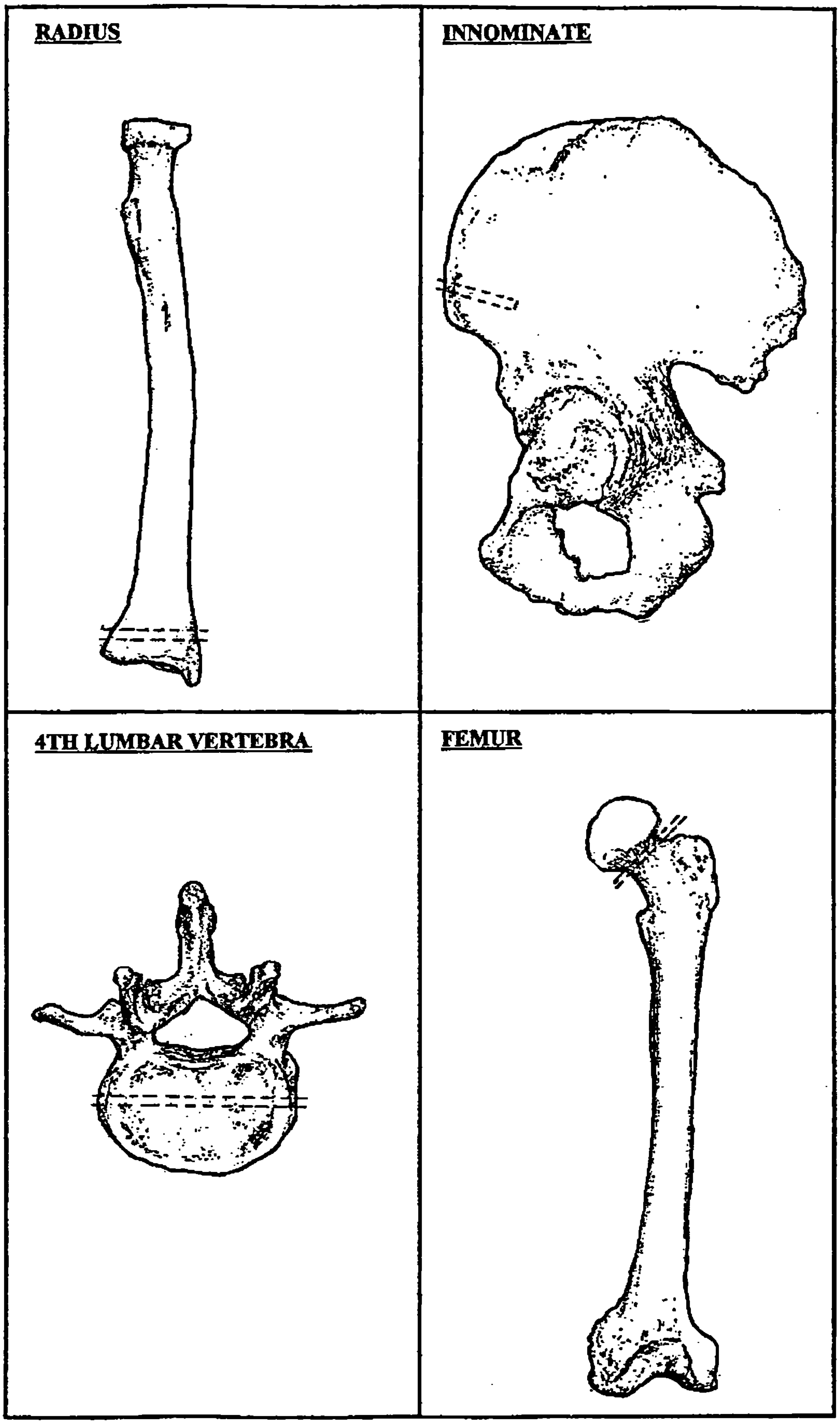


Figure 7.1.1 Regions of the skeleton from which sample material was obtained (after Bass 1987).

Skeleton Number	4th L. Vert.	Proximal Femur	Distal Radius	Iliac Crest	No. of Bones
No Number	✓	✓	✓	✗	3
2	✗	✗	✗	✗	0
6	✗	✗	✓	✗	1
9	✗	✗	✓	✗	1
11	✓	✓	✓	✓	4
24	✓	✓	✓	✓	4
26	✗	✓	✓	✗	2
28	✓	✓	✓	✓	4
32	✗	✓	✓	✓	3
34	✗	✗	✗	✗	0
44	✓	✓	✓	✗	3
46	✓	✓	✓	✓	4
48	✗	✗	✓	✗	1
52	✗	✓	✓	✗	2
54	✓	✓	✓	✓	4
56	✓	✓	✗	✓	3
60	✓	✓	✓	✗	3
62	✓	✓	✗	✓	3
64	✗	✗	✗	✗	0
72	✗	✓	✓	✗	2
89	✓	✓	✓	✓	4
91	✓	✓	✗	✓	3
92	✗	✗	✗	✗	0
96	✓	✓	✗	✓	3
99	✗	✗	✗	✗	0
100	✓	✓	✓	✓	4
101	✗	✓	✓	✓	3
114	✗	✓	✗	✓	2
116	✓	✓	✗	✓	3
118	✓	✗	✓	✗	2
119	✓	✓	✓	✗	3
120	✗	✗	✗	✗	0
122	✗	✗	✗	✗	0
136	✓	✓	✗	✓	3
137	✓	✓	✓	✓	4
140	✓	✓	✓	✓	4
150	✓	✗	✓	✓	3
155	✓	✓	✓	✓	4
157	✓	✓	✓	✓	4
159	✓	✓	✓	✗	3
161	✓	✓	✓	✗	3
165	✓	✓	✓	✓	4
167	✓	✓	✓	✓	4
169	✗	✗	✗	✗	0
171	✗	✗	✗	✗	0
175	✓	✓	✓	✓	4

Table 7.1.1 The number of skeletal elements available from each skeleton from Redcross Way.

7.2 Preliminary Work

This section describes the initial work that was carried out prior to the application of various techniques detailed later within this chapter. Prior to sectioning all bones were examined for evidence of osteoporosis related fracture. None of the bones which are included in the present study were affected by such a fracture. Fractures which may be due to osteoporosis were not seen in any of the sample material from Redcross Way. However, some skeletons were very poorly preserved. One possible vertebral crush fracture was seen from the samples from Farringdon street. The bone in question was poorly preserved and this diagnosis is far from sure. Poor preservation prevented a sample being taken from this skeleton.

7.2.1 Sample Sectioning

Bone samples were sectioned on completion of all the non-invasive investigative techniques mentioned previously. A plane parallel slice of 5 mm thickness was cut from the area of interest of each bone studied (Section 7.8). Sections were made so that the internal structure could be examined Section 7.5.2), and base-line data calculated (a density calculated using weight and volume, see (Section 7.3.1) and cortical bone measured (Section 7.6). A water-cooled low-speed diamond saw was used to obtain the slices (Labcut 1010 D.R. Bennett Ltd. Leicester). To limit the damage to the bone, a mixture of 70% Industrial Methylated Spirits (IMS) and 30% distilled water was used in the water tray. This inhibited the growth of potentially destructive organisms whilst the bone was damp, and speeded the drying of the bone. Bones were clamped securely using a variety of metal clamps with screws, to prevent damage to either the bone or equipment due to movement during sectioning. To avoid crushing the region of interest, samples were clamped away from the region to be studied. The practice of clamping the bone away from the region of interest has been recommended by previous workers (Jayasinghe *et al* 1994). This method of sectioning bone is not destructive, very little bone is lost and it is easy to restore the bone.

It was possible to clamp the 4th lumbar vertebra and the radius so that a slice could be cut directly from the whole bone. However, both the iliac crest and the femur were too bulky to be clamped directly onto the saw. A smaller piece of these two bone types containing the region of interest was cut off with a band saw. The smaller piece of bone was then clamped and a slice removed with the low-speed diamond saw. The exact region of each bone from which a sample was obtained is described in Section 6.1. All bone slices were air dried and then stored in individual plastic boxes to prevent any damage, particularly in the delicate trabecular region. Very delicate samples were additionally wrapped in acid free tissue paper. Illustrations of bone slices obtained from each skeletal element, together with the data gained from their analysis are shown in Section 7.8.

7.2.2 Photography

Photographs of both sides of all bone slices were obtained to aid base-line data collection and for use with stereometric analysis (Figure 7.8.1). Slices were placed on a tilting stage with measurable degree of tilt (Figure 7.2.1). The camera was mounted in a fixed position perpendicular to the horizontal base of the tilting stage. A scale was placed next to the bone to provide a measure of the magnification produced by the photography. The scale was aligned parallel to the rotation axis of the tilting stage to ensure that the length of the scale on the photograph was not distorted by the rotation. The maximum angle between stage and the horizontal was 4.5°. To create a stereo-pair image, two photographs were taken of the cut surface which was tilted in opposite directions between exposures. The total angle between two photographs of a stereo-pair image was therefore 9°. The tilt angle was checked by placing a surface mirror on to the tilting stage and measuring the displacement along a horizontal surface of a reflected light beam shone vertically from the position of the camera. The tilt angle was then calculated by simple trigonometry.

An Olympus OM2 35mm camera fitted with an 80mm macro lens was used to photograph the bone slices. The camera was set so that a picture of the entire bone slice could be obtained. A very small aperture was used to ensure that a large depth of field was gained and the total thickness of the sample was in focus. The printed pictures had a size of 5 × 7 inches which produced images approximately 2½ times the actual size of the bone slices. Four photographs were obtained from each slice providing a stereo-pair image for each side of the bone slice.

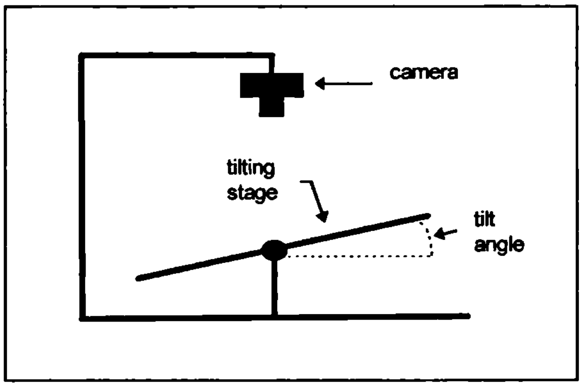


Figure 7.2.1 Schematic diagram of the stage set-up.

7.2.3 Radiographs

The skeletal elements from Redcross Way were radiographed twice, once as a whole bone (Figure 7.2.2) and once as a bone slice (Figure 7.2.3). Those from Farringdon Street were radiographed simply to provide a record for MoLAS. The equipment used was a Todd Research Ltd. X-ray cabinet. In order that the X-rays could be used quantitatively, an aluminium step wedge was placed next to the bone as a standard. The radiographs produced through the methods outlined in this section were used for optical densitometry (Section 7.3.3), the Singh index (Section 7.5.1) and the cortical index (Section 7.6.3). Two wedges were made in the Department of Medical Physics workshop University College London. One wedge was made for use with whole bones, and had 15 thicknesses from 1 mm to 15 mm, increasing in 1 mm intervals (Figure 7.2.2). Each step had an area 15 mm wide by 10 mm long (Farquharson *et al.* 1997). The other wedge was made for use with the bone slices, and had 15 thicknesses from 0.2 mm - 3 mm, increasing in 0.2 mm intervals (Figure 7.2.3). The film used was Kodak Industrex AX Ready pack X-ray film. Experiments were carried out to determine which were the best settings for each bone type. All the bones were then radiographed using these settings, which are given in Table 7.2.1.

Skeletal Area	Settings		Time	
Femur, whole bone	60 Kv,	3μA	30	seconds
Radius, whole bone	50 Kv,	3μA,	35	seconds
4th L. Vertebra, whole bone	50 Kv,	3μA,	35	seconds
Iliac crest, whole bone	50 Kv,	3μA,	35	seconds
All bone slices	60 Kv,	3μA	55	seconds

Table 7.2.1 Settings of the X-ray equipment.

A 0.2 mm aluminium filter was used with all radiographs obtained. This filtered out secondary X-rays, which can cause interference and shadowing, giving a crisper image. All samples were placed on the third shelf of the X-ray cabinet to obtain the optimum distance between the sample and the X-ray tube. To ensure that each sample could be readily identified on the radiographs, lead numbers were used to give each bone sample the skeleton number issued by MoLAS. As development time and temperature of chemicals used influence the appearance of radiographic images, the utmost care was taken over development procedure. A temperature-controlled development tank was used and each stage of the process carefully timed. After several test developments had been carried out, a standard set of processing times was established to give the clearest images. The processing times are given in Table 7.2.2. All the films were air dried.

Developer	Stop bath	Fixer
8 minutes	1 minute	4 minutes

Table 7.2.2 Processing times of radiographs.

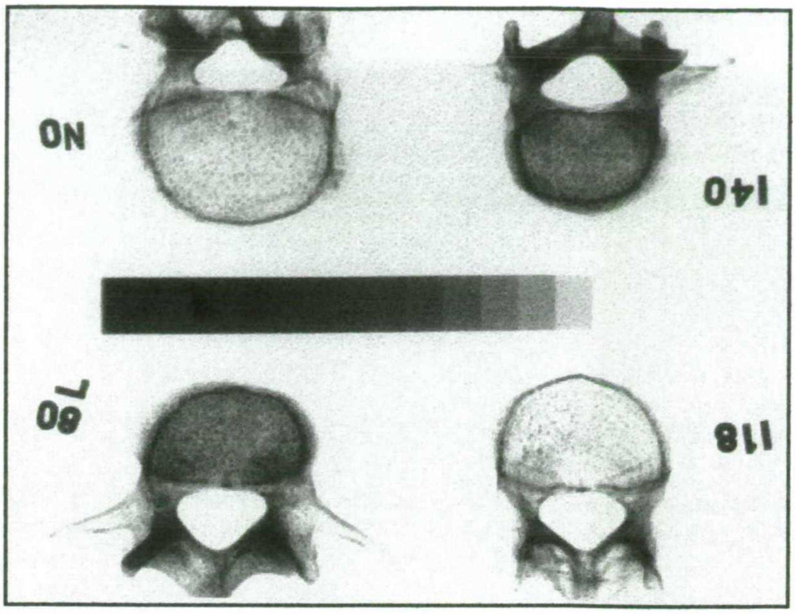


Figure 7.2.2 Positive X-ray images of the 4th lumbar vertebral body with large step wedge.

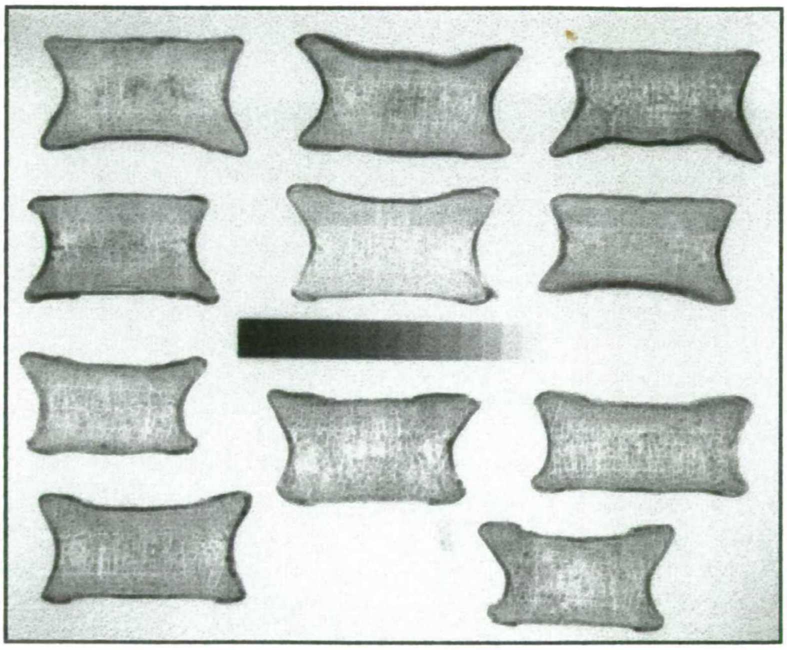


Figure 7.2.3 Positive X-ray images of the 4th lumbar vertebral body bone slices with small step wedge.

7.3 Methods for the Determination of Bone Density

7.3.1 Base-line Density Data

'Base-line density' refers to the bone density calculated from the weights and volumes of bone slices. Base-line density data for whole bone (including both cortical and trabecular bone) slices was calculated for the femoral neck, vertebral body, radius and iliac crest, and trabecular bone density was obtained, following the removal of a known area of trabecular bone, from the femoral neck and vertebral body. Trabecular bone density was not calculated separately in the case of samples obtained from the distal radius and iliac crest. The sample slices obtained from these regions were so small it was considered that attempting to remove the trabecular bone would completely destroy the samples. For the material from Farringdon Street whole bone density was calculated for all the vertebral body slices obtained. Trabecular bone density was only calculated for 92 of the vertebral slices. The complete sample was not done as calculating trabecular density is destructive and some samples were preserved for future study.

This form of density estimation should provide a value which is freer from artefact than any of the methods involving X-ray or X-ray photon measurements. The base-line density data allowed comparisons to be made with all other investigative techniques applied to the sample material. Density was calculated on the basis of surface area, thickness and weight of the bone slices used for most other investigations, so that results would be directly comparable. To obtain the base-line data on whole bone density, slices were weighed, their area calculated, and their thickness measured to obtain whole slice density (g cm^{-3}). An area of trabecular bone was removed in order that trabecular density (g cm^{-3}) could be calculated. Some bone slices were excluded at this stage of the study because preservation was not optimal, for example some slices had parts of the cortex missing.

7.3.2 Whole Bone Density

The pairs of photographs obtained for stereometric examination of the bone structure (Section 7.5.3) provided the means by which the average cross-sectional area of the bone slice could be obtained without causing damage to the bone. Photographs of both cut surfaces of the bone had been obtained, allowing the surface area of both cut sides of the bone slice to be calculated. The surface area of both sides of the bone slice was needed for the density calculation because there are slight differences of the two cut surfaces of each bone slice due to the thickness variation across the bone elements examined. This can be seen in Figure 7.8.1. Density was calculated in two different ways.

7.3.2.1 Method 1

Careful tracings of the outline of the photographs of the two cut surfaces of each bone slice were made onto thick tracing paper and cut out using a scalpel. An area of tracing paper equivalent to 1 cm^2 of bone, according to the scale on the photographs, was cut out of each sheet of paper and weighed (a). The paper representing both cut sides of the bone slice was then weighed (P_1 and P_2 respectively). The average cross-sectional area of the cut surface (A*) in cm^2 is then given by:

$$A^* = 0.5 \times \left(\frac{P_1}{a_1} + \frac{P_2}{a_2} \right)$$

A correction factor was applied to A^* because the photographs were taken at a tilt angle of 4.5°. The true average cross-sectional area of the cut surface (A) is given by the following equation:

$$A = \frac{A^*}{\cos(4.5)} = \frac{A^*}{0.9969}$$

If uncorrected, the percentage error in the area is equal to 0.31%. The weight (W) of each bone slice was measured with an electronic chemical balance and recorded in grams to three decimal places. The thickness of the bone slice (T) was measured with digital callipers and recorded in centimetres. For each bone slice the thickness was measured twice at opposite ends of the slice to check that the thickness did not vary across the bone slice. None of the bone slices had a thickness variation in excess of 0.01 cm. The whole bone density (D) in g cm-3 is given by:

$$D = \frac{W}{AT}$$

7.3.2.2 Method 2

The first method used, although accurate, was time consuming and an alternative method was sought for calculation of density of the vertebral bodies obtained from the Farringdon Street excavation. A computer system that calculated the surface area of images was made available by Dr Peter Trigg of the Wellcome Research Laboratories, Department of Anatomy and Developmental Biology, University College London. The equipment was developed by Dr Trigg to allow the calculation of cell areas from images.

Photographs of the vertebral body slices, which had been taken previously (Section 7.2.2), were placed on the drawing board and covered by a sheet of acetate to prevent damage to the images during analysis. A hand set which contained a set of cross-hairs was used to trace around the outline of the bone. The surface area for both cut surfaces were then computed and the average area was then calculated from these two results for each bone slice. The density was then determined in the same way as Method 1.

7.3.2.3 Reproducibility

The reproducibility of both techniques for obtaining bone density was then calculated, by taking one of the photographs and repeating the area calculation of one of the cut surfaces of a bone slice ten times. Standard deviation and coefficient of variation were calculated (Table 7.3.1).

	Standard Deviation	Coefficient of Variation
Method 1 (tracing)	0.055	0.521 %
Method 2 (computer)	0.031	0.257 %

Table 7.3.1 Standard deviation and coefficient of variation on ten repeat analyses of the area of a bone slice.

Method 2 (computer) proved to be slightly more accurate than Method 1 (tracing), even though great care had been taken over this work. This is probably because with tracing there were more stages at which error might be introduced, for example tracing of the surface area and cutting out with a scalpel.

7.3.2.4 Trabecular Bone Density

Data were also obtained for trabecular bone density of the femoral neck and vertebral body. This allowed the pattern of bone loss from across the whole bone (including the cortex) and trabecular bone to be investigated separately.

The trabecular bone density (D_T) was obtained by removing a known volume (V) of trabecular bone from the bone slice and then re-measuring the weight of the bone slice (W_N). The trabecular bone density is then given by:

$$D_T = \frac{W - W_N}{V}$$

A region of trabecular bone on the cut surface of a bone slice of 1.0 cm by 2.0 cm was chosen for analysis. This 'area' was then cut from the bone slice using a dental drill and/or surgical scissors. The volume (V) of trabecular bone was then determined by:

$$V = 1.0 \times 2.0 \times T$$

The region from which the trabecular bone was removed from each bone slice equated exactly with the measurement volume which the collimation geometry had been set to record using LAXS (Section 7.3.5), and that used for the calculation of trabecular density using optical densitometry (Section 7.3.3). To ensure that the area of trabecular bone investigated was precisely the same as in other investigative methods, radiographs used during optical densitometry analysis were studied. The radiographs used for calculation of density had been carefully marked with the measurement area. A template was made of the measurement area, placed on the bone slice, and surrounded by masking tape to mark the measurement area.

Experiments to determine the best way to accurately remove the trabecular bone, causing as little damage as possible, were carried out on scraps of bone using both a dental drill (Faro model 000485) fitted with a trephine head and a pair of surgical scissors. The dental drill was found to be most effective on the sturdy bones with substantial trabeculae, but damaged fine trabecular bone. In turn, the scissors did not perform satisfactorily on areas of robust bone but good results were obtained on delicate trabeculae. On some bones a combination of cutting with the dental drill and the scissors was applied.

7.3.3 Optical Densitometry

The radiographs which had been produced, for both whole bones and bone slices from Redcross way (Section 7.2.3), were analysed using a light densitometer in the Department of Medical Physics. With this method the film is placed between a source of light and a photoelectronic cell with a calibrated output. The optical densitometer used had a 3 mm diameter aperture. Three measurements were taken from each step in the wedge, from which the mean was found. The mean values were then plotted as a function of aluminium thickness. A curve was then fitted to these points using a quadratic regression procedure (Figure 7.3.1). Each bone sample was measured using the optical densitometer, using a matrix of 2×5 measurement positions, and the mean determined from the ten measuring positions. This mean value was then read off the step-wedge calibration curve, and the sample allocated an equivalent thickness of aluminium in millimetres.

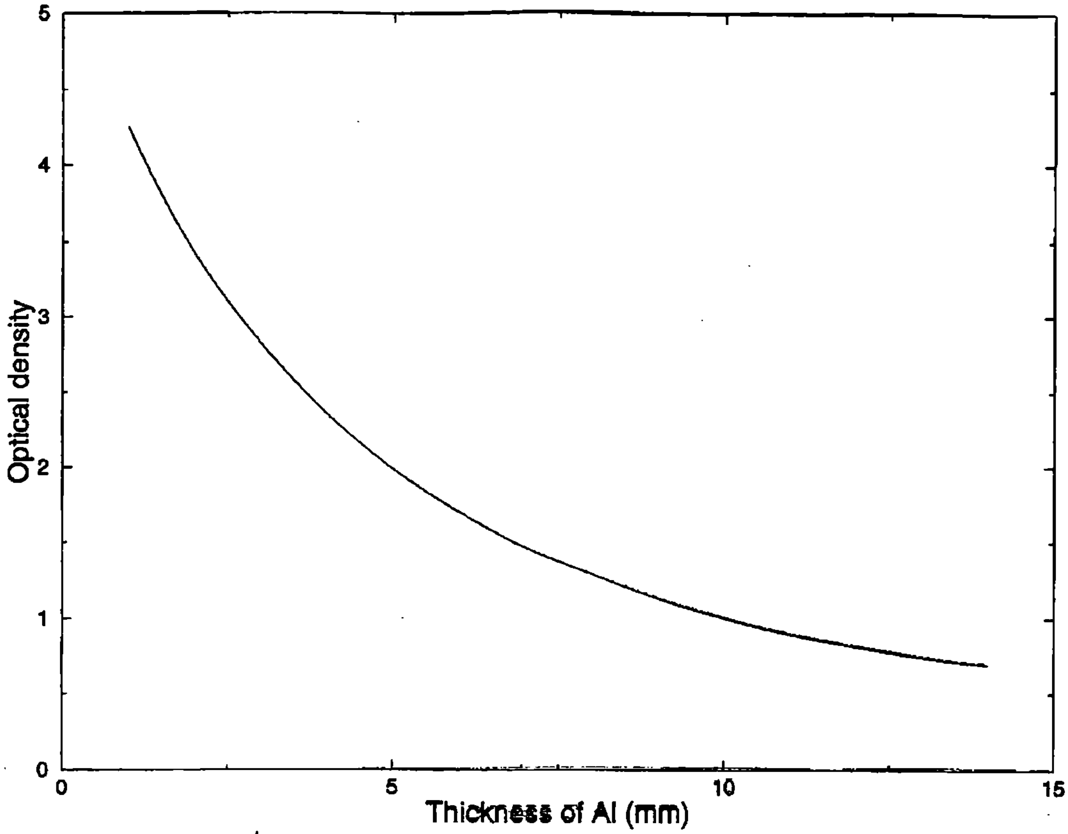


Figure 7.3.1 Equivalent thickness of aluminium plotted against optical density.

The equivalent thickness of aluminium can be used as a relative measure of bone density.

7.3.4 Dual Energy X-Ray Absorptiometry (DEXA)

DEXA was developed for clinical use (Section 2.4.4.2), and has been applied to archaeological material in a number of previous studies (Section 5.2.2). The area of interest is scanned using two energies of radiation that are absorbed by the soft tissue and bone. Computer analysis of the absorption patterns allows the measurement of bone mineral content and density. The way in which absorption patterns are analysed means that the bone mineral density is expressed as grams of hydroxylapatite per cm^2.

Permission was kindly given to use the DEXA equipment at St. Mary's Hospital, London for the present study. The machine at St. Mary's is a Lunar DPX-L (Lunar Corporation, Madison, Wisconsin). The DPX-L has various scanning options depending on the site of the body that is being scanned. It also possible to carry out scans of varying speeds which will give slightly different resolutions. Problems were anticipated with using the DEXA equipment on archaeological bone, because normal DEXA calculations assume there is soft tissue present and that all mineral species encountered are hydroxylapatite. It is probable that the archaeological bone used in the present study did not satisfy these two conditions. However, the sample material was examined for diagenetic change (Section 7.4) and those bones with diagenetic alteration were excluded from the present study. Estimating tissue replacement would be difficult and would undoubtedly introduce error into the calculations.

Advice was sought from the Applications Department at Lunar Corporation for the best methods to employ the Lunar DPX-L on the sample material available. Lunar Corporation recommended that the 'forearm option' was used when performing scans for all bone specimens as it can be used in air providing the tissue equivalent platform made of delrin is included in the scan. Delrin (Acetal/Celcon) is a homopolymer material. With the forearm option, calculations made by the machine did not assume significant amounts of fat and soft tissue. All bones were scanned using the same settings (Table 7.3.2).

Scan Mode	Slow
Scan Type	DPX-L
Collimation (mm)	0.84
Sample Size (mm)	0.3×0.6
Current	(μA) 150

Table 7.3.2 Settings of the DEXA equipment.

Initial results from the DEXA showed that the bone mineral density varied for repeat measurements with machine settings on the same sample. An estimation of the precision of the DEXA measurements was made by recording ten bone mineral density readings of a chosen bone sample over the same region. This was performed for seven bone samples which had produced bone mineral density values in the range of 0.032 g cm^{-2} to 0.9 g cm^{-2}. The mean and standard deviation of the readings were calculated from the ten measurements on each sample. Assuming the measurements are normally distributed, there is a 95% confidence level that a bone mineral density reading will lie within ± two standard deviations of the mean. Two standard deviations were expressed as a percentage of the mean for the value of the precision and plotted as a function of the mean bone mineral density (Figure 7.3.2).

This shows that the precision of the measurements on bones decreases significantly for bones with low mineral density.

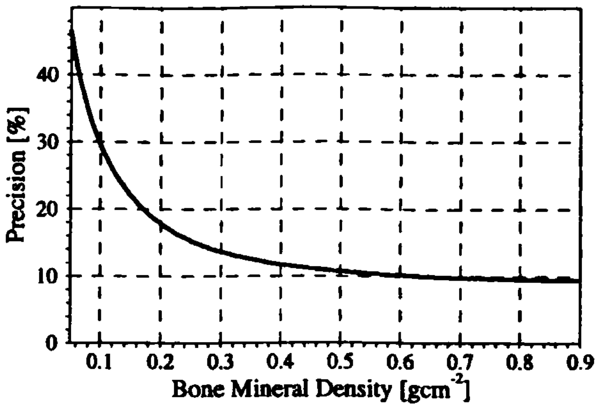


Figure 7.3.2 Estimation of precision as a function of bone mineral density (Farquharson *et al.* 1997).

Details of the patient had to be given before a scan could commence. This information on age, height, weight, sex, race and health are all taken into account by the equipment software when calculations of bone mineral density are made. It was decided that the same details would be given for all individuals because it would be impossible to accurately estimate all the input parameters for each individual. For example, there could be significant inaccuracies in determining the weight and height. This ensured that all calculations performed by the computer are comparable within the sample set investigated in the present study. The individual details are given in Table 7.3.3.

Age:	45
Sex:	Male
Weight (kg)	70.0
Height (cm)	160
Ethnic:	White

Table 7.3.3 Details of age, sex, weight, height and ethnicity given for all DEXA analyses.

The values in Table 7.3.3 were selected with the assistance of the staff at St. Mary's, and represent details of an average individual. All bones were scanned twice. After the initial scan, each specimen was turned over and scanned at the same spot from the other side. This was not possible with the iliac crest, because of its shape, so a scan was simply repeated at the same point.

The manual analysis option was selected for use on all individuals, allowing a specific area to be carefully defined before a value for bone mineral density was determined by the DEXA software.

All bones were scanned across the area marked by a thin pencil line (Section 7.1). Great care was taken to define the region of interest on the monitor, and to ensure that this coincided with the same area defined by pencil on the bone. This proved to be very difficult as the image on the screen is slightly distorted by the method of analysis used in the software. It was stated by the manufacturers that such pictures should not be used for visual analysis, so a marker was scanned with the bone, indicating the location of the region of interest. A pair of unbent paper clips were used for this purpose.

7.3.5 Low Angle X-ray Scattering (LAXS)

Low Angle X-ray Scattering (LAXS) is an energy dispersive diffraction technique upon which research is being carried out by the Department of Medical Physics and Bio-Engineering at UCL for possible use in early detection of osteoporosis. It is still at the laboratory stage and initial results indicate that the radiation dose may be too high to be of clinical use. This is the first time that the technique has been applied to archaeological bones.

Low angle X-ray scattering measurements were carried out on two of the bone sites studied. These were the femoral neck and the vertebral body. It was not used on the iliac crest or radius. Whilst in theory it would be possible to alter the collimation geometry and set up the equipment so that the measurement volume fitted within the cortex of these bones, in practice there was not enough time available on the equipment to allow this to be done. On the iliac crest and radius, the measurement volume defined by the collimation geometry often included the cortex of the bone and in some cases fell outside the cortex.

As the LAXS equipment used is in a developmental stage the equipment is set up to assume no soft tissue. This is a distinct advantage with archaeological bone which obviously has no soft tissue, and helps reduce possible errors.

The experimental set up of the LAXS system is given in Figure 7.3.3. The samples were positioned such that the measurement volume would be in the centre of the bone. The system uses a polyenergetic beam of X-rays produced in an X-ray tube. The geometry used in the measurements was a scatter angle of 5 degrees, slit height 20 mm and the slit width 0.5 mm. The primary and scattered collimation separation distance was 300 mm. The input spectrum from the X-ray tube was 70 Kv. The sample was positioned using a translator device that enabled the sample to be moved at intervals of 0.5 mm until the slice width of 5.0 mm was covered, hence defining a measurement volume within the sample. The total live time pre-set for counting was 1000 seconds which gave good counting statistics for all sets of bones. The mA setting used was 15 mA to give a maximum flux of photons while keeping the dead time of the multi-channel analyser (MCA) to approximately 2%. An energy sensitive detector is placed so as to detect the scattered photons from an object at a fixed angle (Farquharson and Brickley 1997). Dr Michael Farquharson operated the LAXS equipment in the Medical Physics department for health and safety reasons.

Only certain wavelengths (and hence photon energies) will satisfy the Bragg condition for constructive interference from the scattering planes to occur. The energies at which diffraction takes place are detected and an intensity versus energy spectrum can be measured. A plot of the relative intensity of the scattering spectra is produced (Figure 7.3.4). From this plot different minerals can be recognised and their quantities can be calculated. LAXS measurements on bone have the potential to reveal all the mineral components present in the tissue. The results of the measurements using LAXS are expressed in counts of photons.

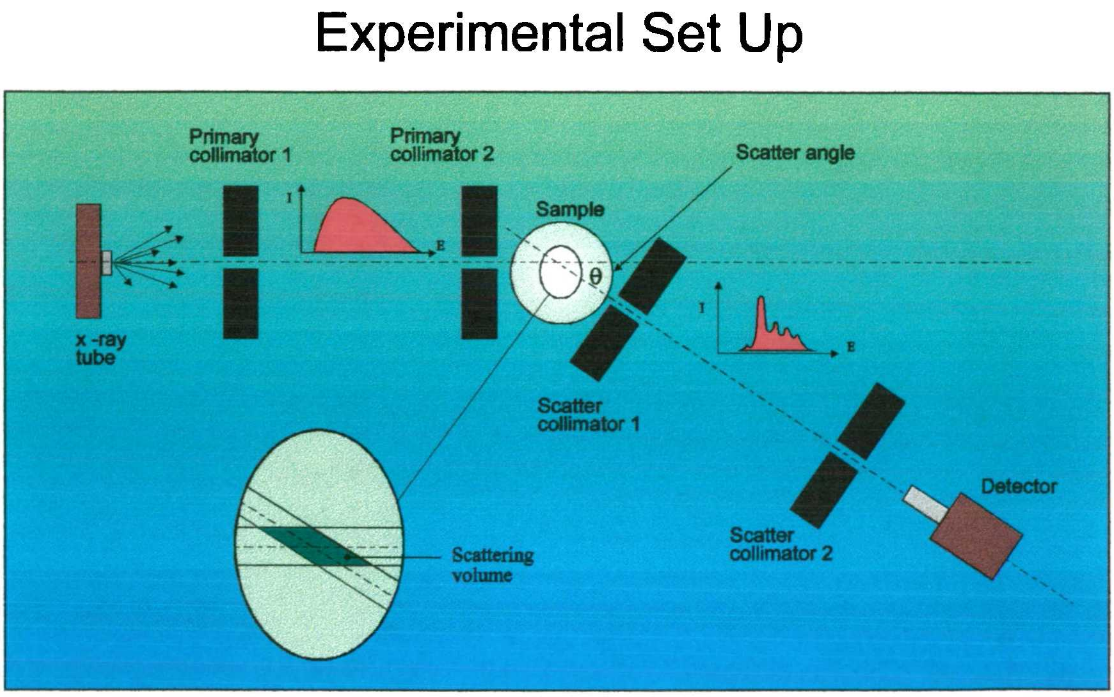


Figure 7.3.3 Schematic representation of the low angle X-ray scattering (LAXS) system (Farquharson *et al.* 1997).

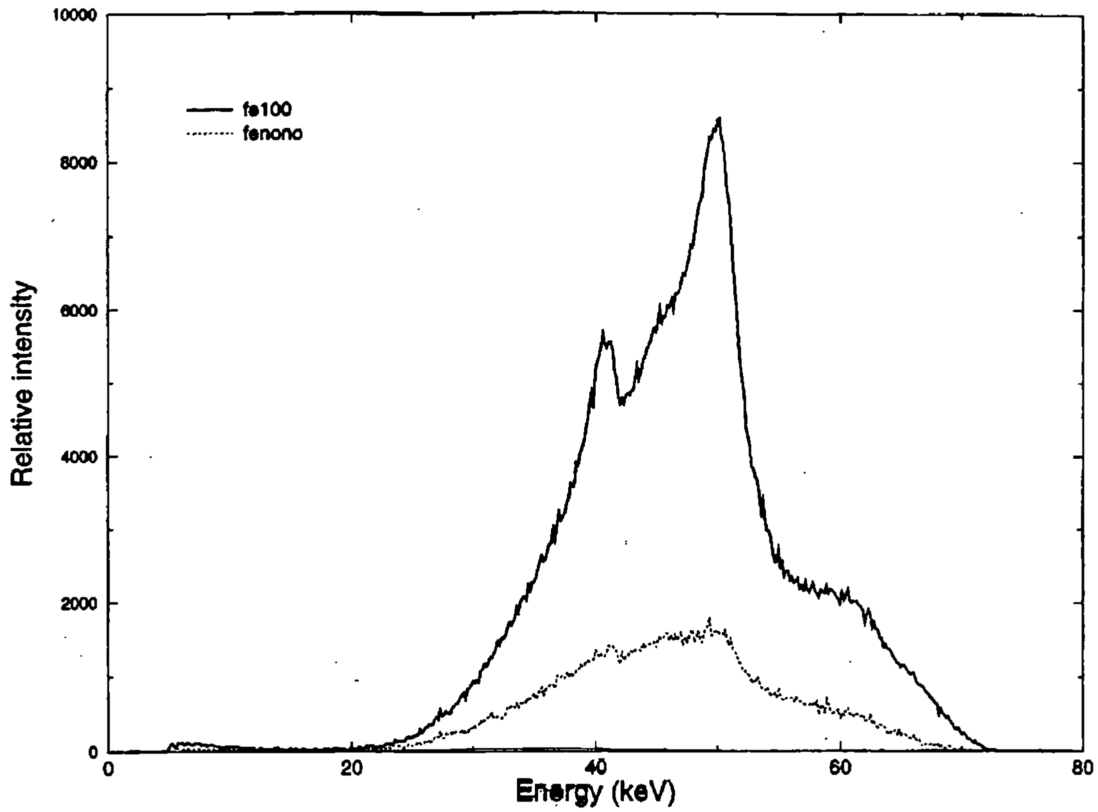


Figure 7.3.4 Plots of a bone with a high mineral content (femur REW 100, Redcross Way) and low mineral content (femur REW no number, Redcross Way).

7.4 Associated Problems of Archaeological Material

7.4.1 Taphonomy

> "Taphonomy is the science of the laws of embedding or burial. More completely, it is the study of the transition, in all details, of organics from the biosphere into the lithosphere or geological record".

This is the definition provided by Russian palaeontologist I. A. Efremov (1940), who coined the term from the Greek word *taphos* (burial) and *nomos* (laws). Taphonomy is an important factor to consider in any study involving archaeological bone material, particularly in osteoporosis research because this condition causes changes in bone density and structure. Factors such as differences in density and structural composition of skeletal elements may dictate the way in which they are affected by taphonomic processes. Different types of bones perform different functions within the body and therefore have structural qualities suited to their roles. It is not only the stiffness and strength of individual bones that will affect their chances of survival but also their size and shape. For example, large thin bones such as the ilium have less chance of surviving intact than small dense bones such as the carpals. Porosity of bone also influences preservation and survival of the bone during both burial and excavation. The bones of older individuals, which tends to become more porous, is less able to withstand stress (Burr 1980). It is likely therefore that the bones of older adults, together with those from very young individuals, may not survive very well within the buried environment. Areas of trabecular bone, which are far more porous than cortical bone, will be much more susceptible to crushing, and it is within such areas that changes associated with osteoporosis are most likely to be manifest (Section 2.3.2). In many instances where the cortical bone is undamaged this will protect the trabecular bone, but in areas such as the vertebral bodies where the cortex is thin crushing may occur. Osteoporotic bones, because of their increased fragility, are therefore more likely to suffer damage after deposition, or during excavation. This could have led to an under representation of bones which have been severely affected by osteoporosis being recovered in a condition which would permit study and identification of the condition.

7.4.2 Diagenesis

The term taphonomy also covers the processes of diagenesis, a term used by archaeologists to describe changes occurring in bone after death. It includes all processes that affect degradation and remineralisation, both in and out of the ground, but excludes the effects of high temperature and pressure (Lapedes 1978, Pate and Brown 1985). Researchers have become aware that structural and compositional changes may affect interpretations made about the age, health status or diet of individuals being examined (Bell 1990, Lambert *et al.* 1985, Thompson 1980). It is now starting to be appreciated that if paleopathological observations are to have any comparability to modern pathological studies, histological and compositional examination must be undertaken. A study involving histological examination of archaeological material by Bell

(1990) concluded that "macroscopic and X-ray interpretations of archaeological bone, both normal and pathological, run the risk of misinterpretation due to its extensive diagenetic change" (p.85).

The presence of diagenetic change is not necessarily detectable from the outward appearance of bone, and bones which appear well preserved may have undergone many changes (Bell 1990, Bell *et al.* 1993, Hanson and Buikstra 1987, Stout and Simmons 1979). As a result of the nature of diagenetic change, analysis of archaeological bone by non-invasive techniques, where bone mineral density is assessed, may be particularly prone to misinterpretation. The only way in which the extent of changes can be observed is through histological examination, or investigation of mineral composition through techniques such as X-ray diffraction (XRD) or micro-probe analysis.

Many possible factors influencing the appearance and survival of archaeological bone have been discussed in the literature, including soil chemistry and chemical weathering (Pate and Hutton 1988), the nature and composition of the bone itself (Henderson 1987) and fungal and bacteriological activity (Douglas *et al.* 1987, Hackett 1981, Marchiafavia *et al.* 1974, White and Hannus 1983). However, the precise causes of such changes are still not known. As Garland (1987) observed, no one factor is likely to be responsible, and the changes seen "are certainly the result of interactions between the various chemical and physical factors and biological agents, within the burial environment and the interred bones" (p.120). There are numerous complex processes that can alter the skeleton *post mortem*. Boddington (1987) suggested that such processes be regarded as an interplay between opposing agents of preservation and destruction He remarked that "The intrinsic physical characteristics of the bone are the preserving agencies in this context set against the destructive chemical and physical biological agents within the burial environment" (p.4). The ultimate result of these changes can be fossilisation of the bone, where a perfect replica of an original biological organism is produced in a variety of other minerals. The chemical content bears little relationship to that of the original organism.

7.4.3 Diagenesis in Redcross Way and Farringdon Street Material

In order to eliminate the possibility of diagenetic change influencing results obtained from non-invasive investigative techniques, the sample material was analysed using Low Angle X-Ray Scattering (LAXS), powder X-ray diffraction and electron microprobe.

7.4.3.1 Low Angle X-ray Scattering (LAXS)

LAXS is a technique which can be used for both quantitative and qualitative analysis of the mineral content of the sample (Section 7.3.5 and 7.4.3.1). LAXS was used qualitatively in the present study. The technique relies upon the fact that crystalline material with long range order will diffract X-ray photons and produce a diffraction pattern that is unique to the material under investigation (Farquharson and Brickley 1997). The spectra produced by LAXS showed that there was a variation in the diffraction patterns produced by three of the bone samples from Redcross Way (Figure 7.4.1). This change in diffraction pattern is due to the presence of another mineral species other than hydroxylapatite in the bone sample.

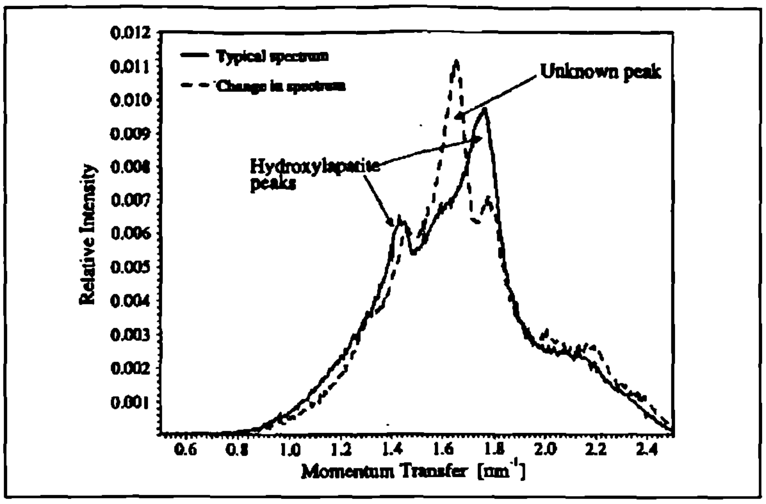


Figure 7.4.1 Typical spectrum recorded from the samples showing characteristic change (Farquharson & Brickley 1997).

The unknown mineral species could not easily be identified with LAXS because at present there is no extensive or readily available reference library of characteristic spectra for mineral species.

Arrangements were made with the Department of Medical Physics for the analysis of sample material from Farringdon Street. However, soon after this work was commenced a fault developed in their X-ray tube which eventually had to be replaced. It was not possible to book any further time on the equipment due to the backlog of work from within the Department of Medical Physics.

7.4.3.2 Powder X-ray Diffraction

In order to determine the mineral responsible for the unknown peaks in the LAXS, conventional X-ray diffraction was applied to selected bone samples in order to assess mineral content. Samples were obtained from five of the bones, two of which had produced a normal LAXS spectra and were included as a control. The other three were samples which had produced anomalous LAXS spectra. A small amount of bone was carefully removed on a clean surface using clean tweezers and scalpel. The fragments of bone were then ground to a very fine powder in an agate mortar and pestle to avoid cross contamination. The mortar and pestle were cleaned scrupulously between each sample and the bench wiped down to avoid any cross contamination.

The X-ray diffraction analyses were performed on the Phillips X'pert diffractometer of the Physics Department, University College London. This used a photon wavelength of 1.5406 Angstroms to irradiate the sample. A spectrum was recorded over a range of scattering angles from 10 to 60 degrees. A peak search was performed using the X'perts software and the lines from the typical hydroxylapatite sample were subtracted from the lines in the sample that produced the extra peak. A material identification routine was run which compares the data from the peak with a library of diffraction data to find a match. The best match was found to be calcium carbonate ($CaCO_3$ JCPDS diffraction file 24-0027). Using the above information, the presence of calcium carbonate can now be recognised in the LAXS spectrum. The control samples contained only hydroxylapatite.

7.4.3.3 Microprobe

In order to understand the diagenetic changes which had taken place, three samples containing $CaCO_3$ were prepared for analysis by electron microprobe. Electron microprobe analysis allows the investigation of small areas up to a few microns, although there may be interference from surrounding areas.

In order that the specimens might be examined with the microprobe, they were embedded in polymethylmethacrylate before being cut and polished. Slices were obtained from each bone adjacent to the area from which bone was obtained for X-ray powder diffraction. The bones were dehydrated before embedding using industrial methylated spirits (IMS). Samples were left for four days in the IMS, then for a further four days in fresh IMS. After dehydration the samples were placed in a 1:1 solution of IMS and methylmethacrylate (MM) monomer for 4 hours. Finally they were moved to a mixture of 95% (by volume) MM monomer and 5% (by volume) styrene destabilised with 0.2% (by weight) 2,2'-azo-bis 2 methylprolprionitrile. The methacrylate was then allowed to polymerise at 20°C for 1 day and 32°C for 8 days. MM is chosen for embedding bone because it has a very low viscosity which improves infiltration into the bone tissue.

The embedded blocks containing the samples were cut into plane parallel slices with a slow speed water-cooled diamond saw (Labcut 1010 DR. Benett Ltd. Leicester). The side of the block containing the section of bone to be examined was then polished with wet graded carborundum papers. The blocks were finished using a pad with 5µm and 1µm diamond paste on a rotary lap (Kent MK2A Engis Ltd. Maidstone England). This process removed virtually all scratches and topographic variation, providing the blocks with a highly polished surface. The prepared blocks were then carbon-coated to render them conductive. The electron microprobe at the Institute of Archaeology was used. This instrument is a Joel AXJ 8600 Microprobe with 2 spectrometers and 4 crystals (TAP, STRIATE, LIF, PET). The settings used on the prepared samples were TAP and PET.

Secondary electron images were obtained from all three prepared samples (Figure 7.4.2). These pictures show a diagenetic cement infilling space between the trabecular elements. Analyses were made of the trabecular bone and the cement. Analysis of the cement gave a weight percentage of

36.7% Ca, 2.4% Fe, 1.1% from a total of 40.7%. Traces of less than 1% of P, Mg, S, Cl and F were also detected. The analysis of the bone gave a weight percentage of 34.9% Ca and 13.4% P from a total of 51%. Traces of less than 1% of F, Mg, S, Cl and Fe were also detected. The total weight percentages of the analyses are low as the microprobe is unable to analyse for carbonate and hydrous phases. All sample readings produced similar results to those given above. A molecule of calcium carbonate contains by percentage weight 40% Ca and 60% CO_3. The analyses of the cement are consistent with the composition of calcium carbonate. A molecule of hydroxylapatite contains by percentage weight 39.8% Ca, 18.5% P and 41% O and H. The analyses of the trabeculae are therefore consistent with the composition of hydroxylapatite. It is therefore probable that the calcium carbonate detected by powder X-ray diffraction is that seen as a cement infilling voids between trabeculae. The hydroxylapatite within the sample material from Redcross Way does not appear to have been replaced by calcium carbonate or any other mineral species. Small changes cannot be entirely ruled out because of limitations of the methods used, but changes at this level are unlikely to significantly affect results obtained from the techniques employed in the present study.

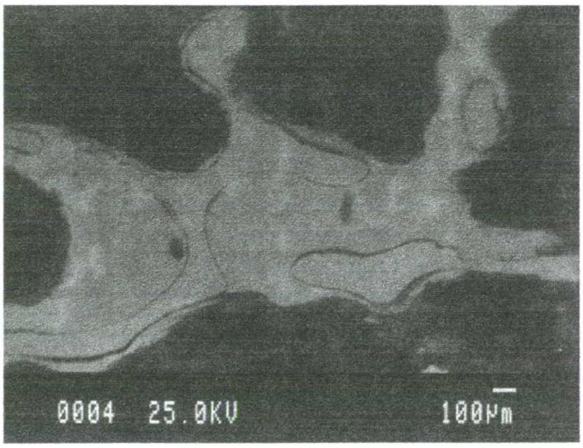


Figure 7.4.2 Secondary electron image of trabecular bone at one of the measuring sites. The slightly darker cuspate shapes are trabecular elements. The infilling material is carbonate cement. The white patches distributed across the cement are highly charged areas. It is probable that these are artefacts due to irregularities in the carbon coat.

The calcium carbonate cements could be observed microscopically and visually. These appeared as creamy white infills in the void spaces of the trabeculae (Figure 7.4.3). It should be noted that most of the trabecular bone within the three analysed samples were free of calcium carbonate cement. However, very small foci of diagenetic change cannot be detected visually.

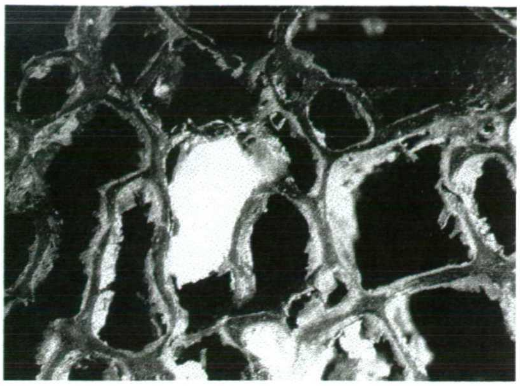


Figure 7.4.3 Calcium carbonate cement infilling void area between trabeculae. This picture was obtained using light microscopy. Field width 3.5mm.

7.4.4 Soil Contamination

When sectioned, (Section 7.4.4) the vertebra from Farringdon Street were shown to contain a large amount of 'soil' within the trabecular region. In comparison, the samples from Redcross Way contained much less soil material. This was not apparent from visual examination of whole bone radiographs (Figure 7.4.4). Both bone collections were well preserved and in many cases there was no obvious area of damage. Because the bones are intact it is probable that the soil within the bone samples is due to insitu growth of minerals from water percolating through the bones. The Farringdon Street vertebrae contained so much soil that, in order that the weight could be accurately determined, they had to be cleaned. Samples had to be wetted because the soil had hardened and in many cases was adhering firmly to the trabeculae. Bone slices were placed in carefully labelled petri dishes containing 70% IMS, 30% distilled water to limit any damage which might have been caused by wetting, and a fine paintbrush was used gently to remove soil. When clean, the bone slices were allowed to dry in air before being re-weighed. The percentage of the sample slice weight which was accounted for by soil is shown in Table 7.4.1.

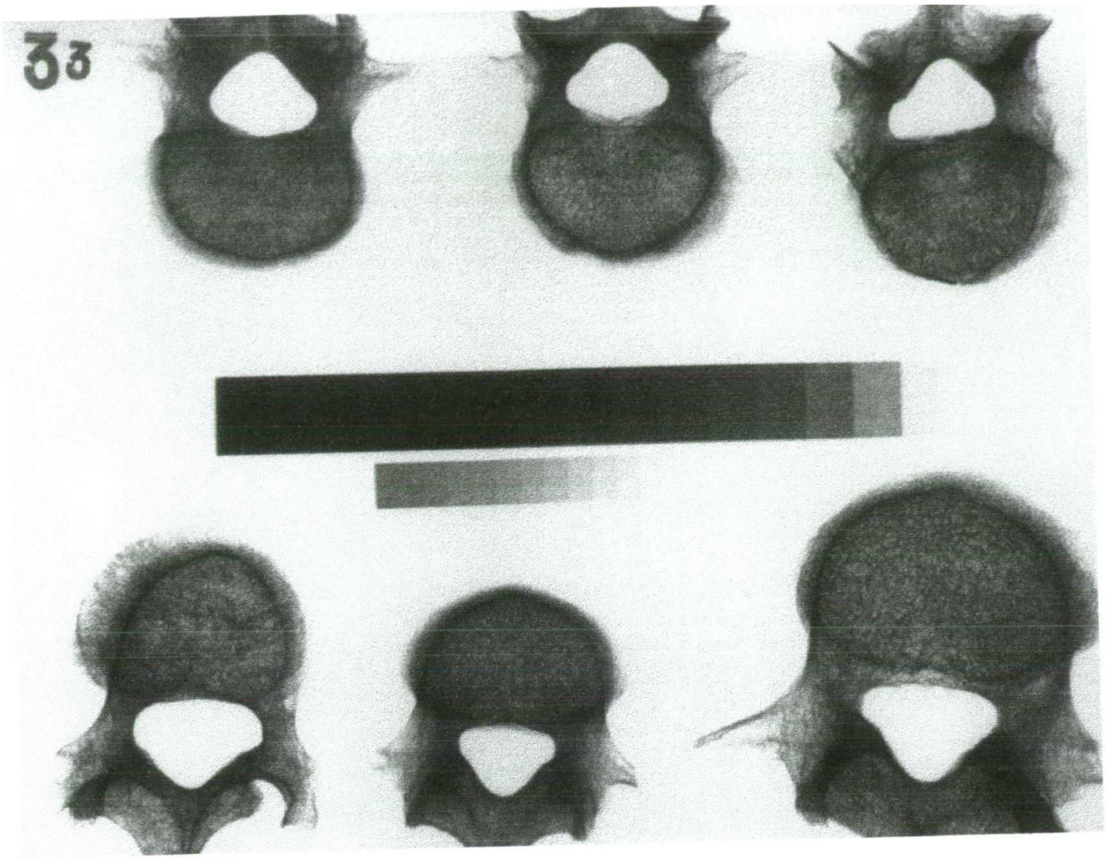


Figure 7.4.4 Whole bone radiographs of fourth lumbar vertebrae from Farringdon Street. The amount of soil by weight percent is detailed below. Top row left to right 1995 (0%), 2116 (0%), 2132 (0.1%). Bottom row left to right 2288 (11.7%), 1586 (1.2%), 1408 (0%).

Sample no.	%weight soil	Sample no.	%weight soil	Sample no.	%weight soil	Sample no.	%weight soil
2332	20.1	1879	1.9	1693	1	2161	0.6
2288	11.7	1753	1.8	2243	1	1441	0.5
1408	10	1326	1.8	1570	1	2055	0.5
1942	8.9	1999	1.8	2049	1	1580	0.5
1521	8.9	1787	1.8	2253	1	1767	0.5
1831	6.4	1671	1.7	1420	1	1125	0.4
1707	6.4	2109	1.7	1903	1	2342	0.4
1621	5.7	1695	1.6	2120	0.9	1771	0.4
1897	5.3	1500	1.6	2185	0.9	1209	0.4
1791	5.1	1649	1.6	1845	0.9	1152	0.4
1946	4.8	1689	1.6	1990	0.9	1298	0.4
1685	4.7	1957	1.6	2130	0.9	1312	0.4
1174	4.6	1417	1.5	1343	0.9	2216	0.4
1360	4	2383	1.5	1155	0.9	1874	0.3
1215	3.9	2058	1.5	2075	0.9	1127	0.3
1781	3.8	1919	1.4	1564	0.9	1637	0.3
1862	3.8	2237	1.4	2063	0.8	1549	0.3
1972	3.7	1578	1.4	1546	0.8	2223	0.3
1976	3.5	1330	1.4	1853	0.8	1634	0.3
1719	3.3	2175	1.3	2158	0.8	1519	0.3
2073	3.2	1200	1.3	2340	0.8	1608	0.3
2083	3.1	1653	1.3	1415	0.8	1366	0.3
2245	3.1	1123	1.2	1913	0.8	1954	0.2
2312	3.1	1860	1.2	1204	0.8	1785	0.2
1635	3	2065	1.2	2126	0.7	1422	0.2
1292	2.8	1938	1.2	1202	0.7	1799	0.2
1281	2.5	1178	1.2	1997	0.7	1336	0.2
2195	2.5	1899	1.2	1709	0.7	1691	0.1
2214	2.5	1586	1.2	1357	0.7	1739	0.1
1591	2.5	1743	1.2	2205	0.7	1454	0.1
1891	2.4	1893	1.2	1606	0.7	2001	0.1
2081	2.4	2122	1.1	2134	0.7	2164	0.1
2193	2.3	1825	1.1	2077	0.7	2124	0.1
1170	2.3	1449	1.1	2009	0.7	1872	0.1
2005	2.2	1673	1.1	1126	0.7	1457	0.1
2053	2.1	1809	1.1	1409	0.7	2263	0.04
2011	2.1	1930	1.1	1278	0.7	2116	0
1610	2.1	1119	1.1	1456	0.7	2298	0
2302	2.1	1991	1.1	2136	0.6	1188	0
1379	2	1952	1.1	2269	0.6	1515	0
1870	2	1793	1.1	1116	0.6	2140	0
2043	2	2165	1	2114	0.6	1428	0
1599	2	1291	1	1925	0.6	1727	0
1589	2	2206	1	2061	0.6	1611	0

Table 7.4.1 The percentage of bone slice weight accounted for by soil before washing, Farringdon Street samples.

The percentage weight of soil given represents an estimate of soil content. Although great care was taken during the sample preparation, it is possible that soil was lost during sectioning and handling of bone slices.

From the 201 bone slice samples obtained from the Farringdon Street collection it was necessary to clean 88% of the slices. There was one individual in which the soil had accounted for 20% of the original bone slice weight. Overall, 1.1% of the sample had 10-20% of the original weight made up by soil. Four percent of the samples had between 5 and 10% of their original weight made up by soil. The largest group (48%) contained those slices with 1-5% of their original weight accounted for by soil. There were also a significant number of slices where there was only a small amount of soil present. 41.5% had 1% or less of their original weight made up by soil. A number of samples (4.8%) had no significant weight change.

7.4.5 Discussion

The work in this chapter shows that diagenetic change has occurred in the sample material examined. Deposition of mineral in the bones was not uniform across the sample material taken from the site at Redcross Way. The results from the LAXS analysis show that an extra mineral component occurs in some samples. Powder X-ray diffraction has shown that this mineral component is calcium carbonate. Analysis with electron microprobe shows that the mineral has been deposited in the void space between trabeculae; no mineral replacement by calcium carbonate was detected in the trabeculae.

The collimation geometry defined in the LAXS analysis in the present study sampled an area of 10mm by 20mm. The occurrence of a calcium carbonate peak will depend upon the proportion of hydroxylapatite and calcium carbonate present within the measurement volume defined by the collimation geometry, because the calcium carbonate signal occupies the same range of the spectrum as LAXS. The current set-up of the LAXS apparatus cannot detect very small amounts of calcium carbonate. The three samples with calcium carbonate peaks were excluded from the study. However, from visual and microscopic analysis (Section 7.5.2) it was clear that there was no major infilling of voids within the trabecular region of any of the Redcross Way samples. The trabecular region in Farringdon Street samples contained some soil material, but this was removed during cleaning. It is possible that this infilling could have protected areas of fragile trabecular bone during burial. Voids in the trabecular region filled with calcium carbonate were not observed in the Farringdon Street samples.

The assumptions made in many of the previous studies of archaeological bone (Section 5) that diagenetic change is uniform across an archaeological site are not valid. At both Redcross Way and Farringdon Street the degree of infilling of voids within the trabecular region was variable. Results obtained from this limited study demonstrate that some form of check is needed when non-invasive scanning techniques are used. For example, non-invasive techniques such as DEXA or optical desitometry from radiographs will produce erroneous results if bone hydroxylapatite has been replaced by minerals with significantly different attenuation values. Similar errors may occur if there is material infilling voids in the trabecular region. LAXS can distinguish between hydroxylapatite and other minerals and therefore this problem can partly be addressed using this technique. However, to detect minerals other than hydroxylapatite using LAXS, it may be necessary to optimise the collimation geometry of the LAXS (Farquharson and Brickley 1997). From the above work one can be reasonably confident that no major diagenetic changes are influencing results obtained from the material examined. Further work on the use of LAXS for the non-invasive detection of mineral change within archaeological bone would be necessary to realise the full potential of LAXS.

This study does not seek to explain how mineral replacement and deposition take place or examine the full range of such occurrences. The work required to provide answers to such questions is far too complex to be undertaken as part of the present study. This work was undertaken simply to demonstrate that such changes do occur.

7.5 Methods for Examining Trabecular Bone Structure

7.5.1 The Singh Index

Details of this technique were first published in 1970 (Singh *et al.*) as a way of assessing trabecular bone loss and osteoporosis from radiographic images. The region used in this technique is the Ward's triangle region of the proximal femur. Six stages were defined, based on the visibility of the five main groups of trabecular structures present in this region, with grade six being normal and one being severely osteoporotic. The various stages are described as follows:

> "Grade six. All the normal trabecular groups are visible and the upper end of the femur seems to be completely occupied by cancellous bone.
>
> Grade five. The structure of the principal tensile and principal compressive trabeculae is accentuated. Ward's triangle appears prominent.
>
> Grade four. Principal tensile trabeculae are markedly reduced in number but can still be traced from the lateral cortex to the upper part of the femoral neck.
>
> Grade three. There is a break in the continuity of the principal tensile trabeculae opposite the greater trochanter. This grade indicates definite osteoporosis.
>
> Grade two. Only the principal compressive trabeculae stand out prominently; the others have been resorbed more or less completely.
>
> Grade one. Even the principal compressive trabeculae are markedly reduced in number and are no longer prominent." (Singh *et al.* 1970, p.463-465).

A series of diagrams illustrating each stage of trabecular bone loss were produced by Singh *et al.* (1970) to accompany this description and allow other workers to use the technique. These diagrams were used in the present study.

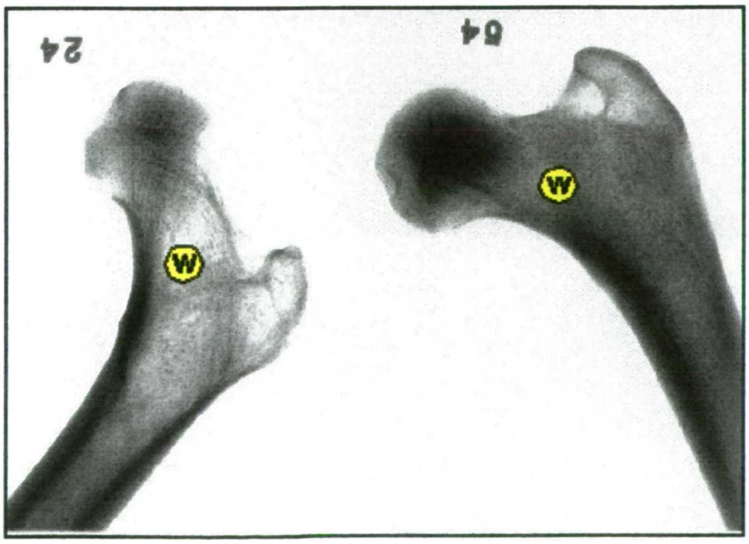


Figure 7.5.1 Positive X-ray image of the proximal femur. The region of Ward's triangle is marked by W.

Radiographs (Section 7.2.3) of all the femoral necks sampled from the Redcross Way material were produced, such as the ones shown in Figure 7.5.1. These were examined and scored according to the Singh Index. After scores had been awarded the results were filed. One month later, the radiographs were re-examined without looking at the results previously awarded, and re-scored. This process was repeated again two weeks later. This re-examination procedure was carried out to check the reproducibility of the method and increase the confidence in the scores awarded.

7.5.2 Analysis of Cut Sections

7.5.2.1 Visual

The bone slices from the 'subsample' (those which were selected for stereometric analysis), were examined visually to ascertain if any changes could be observed between the various age/sex groups and to detect the presence of any diagenetic minerals infilling cavities within the trabeculae. Microcallus formation and free-ending trabeculae, features associated with bone loss, were also looked for and recorded.

7.5.2.2 Microscopic

The trabecular bone in all the bone slices obtained from the vertebral bodies was examined using a dissection microscope. This analysis was carried out to detect the following structures:

a) free-ending trabeculae;

b) microcallus;

c) to detect the presence of any diagenetic minerals infilling cavities within the trabeculae.

Free-ending trabeculae are those which had been completely resorbed in places and are now unconnected at one end to the trabecular bone network. It was considered that non-connection of the trabeculae was a sign of possible osteopenia with bone loss leading to a gradual loss of structural integrity of the bone. Microcallus could be taken as an indicator of sufficient bone loss and loss of structure to cause a failure of the microarchitecture of the trabecular bone.

7.5.3 Stereometry

In the study by Jayasinghe (1991) a detailed analysis of morphological changes in trabecular bone with age was undertaken. After examining a range of techniques for the analysis of the dimensional structure of trabecular bone Jayasinghe concluded that stereometric analysis was the best and simplest approach. The study concluded that there was a significant decrease in horizontal and vertical trabeculae with age. Most importantly, the study by Jayasinghe showed that there was a highly significant decrease in horizontally oriented trabeculae with age and that the length of those remaining increases. In the present study it was decided to determine if this simple and easily measurable index of bone loss could be observed in the material available for study. With complicated structures, such as the network formed by trabecular bone, stereo measurement techniques are important for the correct interpretation of spatial relationships.

The prints were carefully oriented on the photo-carriage of an SFS-3 stereocomparator (Ross Instruments Ltd. Morgansvale Road, Redlynch, Salisbury, Wiltshire UK) so that their tilt axis coincided with the instrument's y-axis (Ross 1986). A trabeculum was identified and the instrument adjusted so that its floating marker lay on the surface of the optical model. The photograph (x,y) co-ordinate and parallax, P, reading for each end of each trabeculum were passed to a personal computer where the real 3D co-ordinates were calculated using the following equation:

$$Z = \frac{\Delta P}{2\sin\left(\alpha/2\right)}$$

Where Z is the height difference between two points, when there was a parallax difference ΔP and an angle α (9°) between the two photographs. These data were displayed on the computer monitor and simultaneously displayed on a map showing the location of each of the measured points. One hundred trabeculae oriented in the medio-lateral and the antero-posterior planes were measured from each lumbar vertebra. An even distribution across the whole of the cut bone surface was ensured by repeated reference to the display on the computer monitor. The co-ordinates of each trabeculae and its length were additionally filed for statistical analysis.

The trabecular lengths were extracted from the data file and pooled according to sex and age at death. Later, the trabecular lengths were extracted from each data file and grouped into the appropriate sex and age at death category. Descriptive statistics and a comparison of the median for each group were carried out.

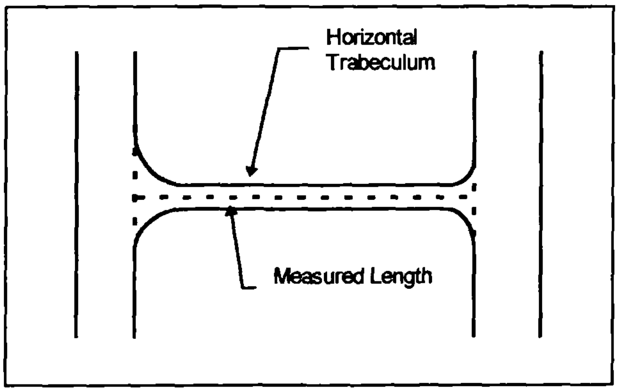


Figure 7.5.2 Schematic representation of the measured length of an horizontal trabeculum.

The ability to repeatedly place the floating marker of the stereocomparator on either end of a 3D trabeculum was tested. Two trabeculae lying at different angles within the bone were selected, and each was measured fifty times. Accuracy was estimated using standard deviation and found to be 0.0735 millimetres (= 1 standard deviation of fifty measurements on the same trabeculum). Defining the exact point at which a trabeculum starts and ends will always be difficult. In the present study, where horizontally orientated trabecular elements were measured, the end of a trabeculum was defined as the furthest point along the bone which did not encroach onto the vertical plate as shown in (Figure 7.5.2).

7.6 Cortical Bone Loss

7.6.1 Introduction

Cortical thickness measurements made from radiographs (Section 7.2.3) have been one of the commonest methods used to determine 'osteoporosis' (bone loss) in previous studies of archaeological material. Such techniques were probably widely applied because of the simplicity of the equipment needed. Often measurements can be made from simple radiographs (Mays 1996), and this negates the need for sectioning which can be problematic when archaeological bone material is involved. In the present study three types of measurement of the cortical bone were obtained from radiographs of the femoral necks from Redcross Way:

a) cortical thickness;

b) cortical index;

c) cortical area.

Besides whole-bone radiographs, 'direct measurements' were made on the actual bone slice, in order that comparisons between the various approaches could be made. A number of regions of the skeleton have been selected in previous studies of cortical bone loss in archaeological material, (Section 5.2). In the present study the femoral neck was selected as it was in this region that all other investigative techniques had been carried out. This would allow direct comparisons to be made with density data. Also it is in this region that osteoporosis-related fracture normally occurs. The femur has been widely studied in investigations of both archaeological material (Carlson *et al.* 1976, Martin and Armelagos 1979, Thompson and Gunness-Hey 1981) and modern populations (Feik *et al.* 1996). The femoral neck is not however the region chosen for analysis of cortical bone loss in clinical studies, and it has not previously been examined in studies of archaeological bone material.

7.6.2 Cortical Thickness

Direct measurements were obtained from cut sections of the femoral neck (Figures 7.8.1 -7.8.3). Considerable variation in the thickness of the cortex around the femoral neck was observed from the sectioned samples. It was therefore decided that measurements should be taken at a number of points around the femoral cortex. Eight points were selected at regular intervals and an acetate template marked with the points at which measurements were made. The template was placed over each of the bone slices and the cortex was measured where the lines crossed the cortex. Measurements were made with callipers in centimetres to three decimal places.

7.6.3 Cortical Index

The cortical index is a way of gaining a measure of cortical thickness, it estimates the percentage of the width of a bone that is occupied by the cortex. The index is calculated using the equation;

$$\text{cortical index} = \frac{(\text{total bone width}) - (\text{medullary width})}{(\text{total bone width})}$$

This methodology was used by Mays (1996) in his assessment of the British Medieval material from Wharram Percy. In the study by Mays the second metacarpal was selected for analysis.

7.6.4 Cortical Area.

The cortical area was determined using the same methodology as that described for the determination of the whole bone area for the calculation of base-line density in Section 7.3.2.18 (Method 1).

7.7 Statistical Analysis

The previous Sections in this chapter have described how various methods have been used to obtain data on the 4th lumbar vertebral body, femoral neck, radius and iliac crest. These data include measures of bone density from direct measurement (base-line density of whole and trabecular bone) and measures of bone density from non-invasive techniques (DEXA, LAXS and optical densitometry), measures of the trabecular integrity (stereometry and Singh index) and measures of the cortical bone (cortical thickness, area and index). These measures can all be considered as variables that describe a characteristic of the same object; a particular skeletal element. Apart from the Singh index, all these measurements are continuous variables. The age of death of the individuals from which the bone originated has also been estimated. This can be considered as a variable, albeit somewhat different in nature than the measurements listed above. As a result of the limitations of the ageing of archaeological bone material, the bones are grouped into age categories. Each age category therefore contains bones of different ages, but all bones within a category are considered to have an age that lies within a distinct age range. As such, these age categories could be considered as sub-groups of the whole sample; the archaeological bone material examined in the present study.

There are two questions that arise when considering the data collected in the present study:

a) is a variable (e.g. the trabecular base-line density) measured on the same object (e.g. the femoral neck) similar or different in two different sub-groups (i.e. two different age categories);

b) what is the relationship between two variables (e.g. the whole-bone base-line density and the LAXS data) measured on the same object (e.g. the radius).

These questions can partly be answered by plotting two of the variables against one another. However, such an analysis can only produce a qualitative measure of the relationship, and this will impair the strength of any conclusions drawn. The relationships can be quantitatively analysed using statistics, and this, if applied correctly, will add more confidence in relationships observed by qualitative analysis. The statistical analysis was performed using the SPSS 6.1 software (SPSS Inc., Chicago, USA).

The two types of statistical analysis performed in the present study, as formulated by the questions above, are discussed in the following two Sections. The relationships between base-line density and another variable, such as LAXS or DEXA data were examined. In most cases there was no need for examining the relationships between more than two variables, because the comparison of all the variables with base-line density is the most relevant and important for the present study.

7.7.1 The Relationship between Two Sub-groups

Statistical tests to determine levels of difference between data derived from each age/sex category were performed. The t-test is a parametric test which has the underlying assumption that the data are normally distributed. Normality of distribution was checked using the Kolmogorov-Smirnov test. This test showed that not all age/sex categories were normally distributed, and for the categories which were not normally distributed, the Mann-Witney U test was performed. This is a non-parametric test and therefore does not have any underlying assumptions with regards to the data distribution. The disadvantage of this test is that it is less likely to find a true difference than a test based on the assumption of normality, such as the t-test. This testing procedure was applied to all data within this section. The non-normal categories were those with smaller sample sizes.

The magnitude of the test statistic provided by the t-test and the Mann-Witney U test provides a quantitative measure of the level of significance of the difference between two populations. The meaning of the test statistic in terms of 'significance' is summarised in Table 7.7.1. These descriptions of significance are maintained throughout for the t-test and the Mann-Witney U test.

Test Value	Level of Significance
> 0.05	not significant
0.01 - 0.05	significant
0.001 - 0.01	very significant
< 0.001	highly significant

Table 7.7.1 Levels of significance of the test statistic from the t-test and the Mann-Witney U test.

7.7.2 The Relationship between Two Variables

The relationship between two variables is normally analysed by regression and correlation. Correlation concerns the strength of the relationship between the values of the two variables. Regression analysis determines the nature of that relationship and enables predictions to be made from it. A correlation coefficient measures the strength of the linear association between two variables (Norušis 1994). Two variables are related if in a scatterplot the points cluster around a straight line. If all of the points fall exactly on a line with positive slope, the correlation coefficient is 1. If they fall exactly on a line with negative slope, the correlation coefficient is -1. The absolute value of the correlation coefficient says how tightly the points cluster around the line. Therefore a correlation coefficient of 0 does not mean that the two variables are not related.

They may be related in a non-linear way. Regression is the technique where data is fitted to a mathematical model. The simplest form of regression is to match the data to a straight line.

To test hypotheses about a regression line the data must satisfy certain criteria (Norušis 1994):

a) the variables measured must be on an ordinal scale;
b) all of the measured variables must be independent;
c) for each value of the independent variable, the distribution of the values of the dependent variable must be normal;
d) the variance (i.e. [standard deviation]^2) of the distribution of the dependent variable must be the same for all values of the independent variable;
e) the relationship between the dependent and the independent variable must be linear.

These criteria are important because any conclusions drawn from the correlation coefficient have the underlying assumption that the two variables have a linear relationship. These criteria were tested, when necessary, by statistical analysis.

It is clear that all the variables measured in the present study, such as base-line density or LAXS data, can all be measured on an ordinal scale. The variables considered did not include repeat measurements on the same bone sample and no analyses of a particular bone element were repeated on a similar bone element from the same individuals. For example, only the right-hand side femur was analysed of each individual. Given these facts, it is very likely that the variables are independent.

The normality, linearity and constant variance were checked by analysing residuals following the methodology described by Norušis (1994). These analyses were performed for all variables for which correlation coefficients and regression lines were calculated.

The residual is the difference between the value observed and the value predicted from the regression analysis. 'Standardised residuals' are calculated by dividing the observed residual the estimated standard deviation for all the residuals. 'Studentised residuals' are calculated by dividing the observed residual by the an estimate of the standard deviation of the residual at that point. The 'studentised deleted residual' is the studentised residual for a case when the case is excluded from the computation of the regression statistics. When there are departures from any of the regression assumptions, they are more easily detected with studentised deleted residuals than the other types of residuals mentioned above (Norušis 1994). Normality was tested by performing K-S (Lilliefors) tests on the studentised deleted residuals. Normality is complied with if the significance of the test is greater than 0.05. For the case of the trabecular base-line density data and LAXS data, females, the significance of the K-S (Lilliefors) test was >0.2. In most cases examined the significances was much greater than 0.05, but some cases the test was inconclusive with significances very close to 0.05.

To check if the variance of the dependent variable was the same for all values of the independent variable, the studentised deleted residuals were plotted against the predicted values. The predicted value refers to the corresponding value of the dependent variable as calculated by linear regression analysis. The criterion for constant variance is met if the studentised deleted residuals appear to be randomly scattered around a horizontal line through zero. Figure 7.7.1 shows a studentised deleted residual/ predicted value plot for the case of the trabecular base-line density data and LAXS data for the females. This shows a random scatter of the values around a horizontal line through zero, demonstrating that the criterion for constant variance was met. All studentised deleted residual/ predicted value plots showed random scatter of data points.

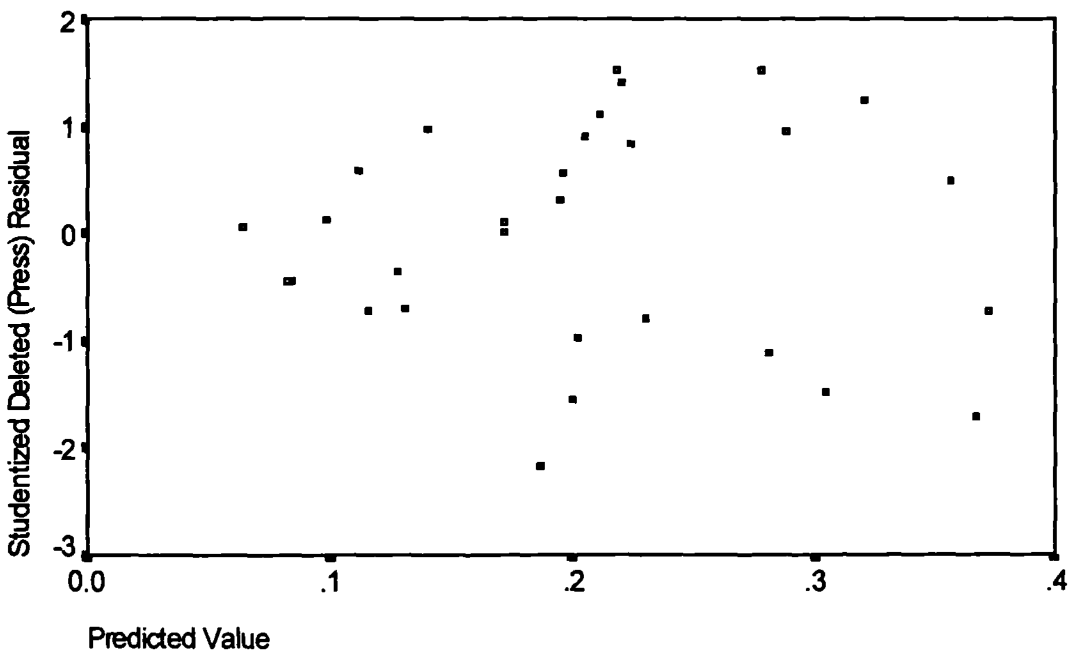


Figure 7.7.1 Studentised deleted residual/ predicted value plot for the trabecular base-line density data and LAXS data for the females.

The linearity was checked initially by plotting the dependent variable against the independent variable. Least-squares regression lines were used to aid this analysis. A least squared regression line is the line that will have the smallest sum of the squared vertical distances between the points and the line. Examples of these regression lines are given in Sections 8, 9 and 10. For all variables for which correlation coefficients were calculated, the data always clustered around the regression line.

The normality of distribution was also examined with studentised deleted residuals using a 'Q-Q normal probability plot'. The Q-Q plot show the observed of the studentised deleted residual value plotted against the value of the studentised deleted residual that is expected if the data had a normal distribution. Figure 7.7.2 shows a Q-Q plot for the trabecular base-line density data and LAXS data for the females. The data in this plot all fall close to the regression line. Large departures from the regression line would suggest that linearity was not met. No significant departures were observed for any of the Q-Q plots produced during the statistical analysis.

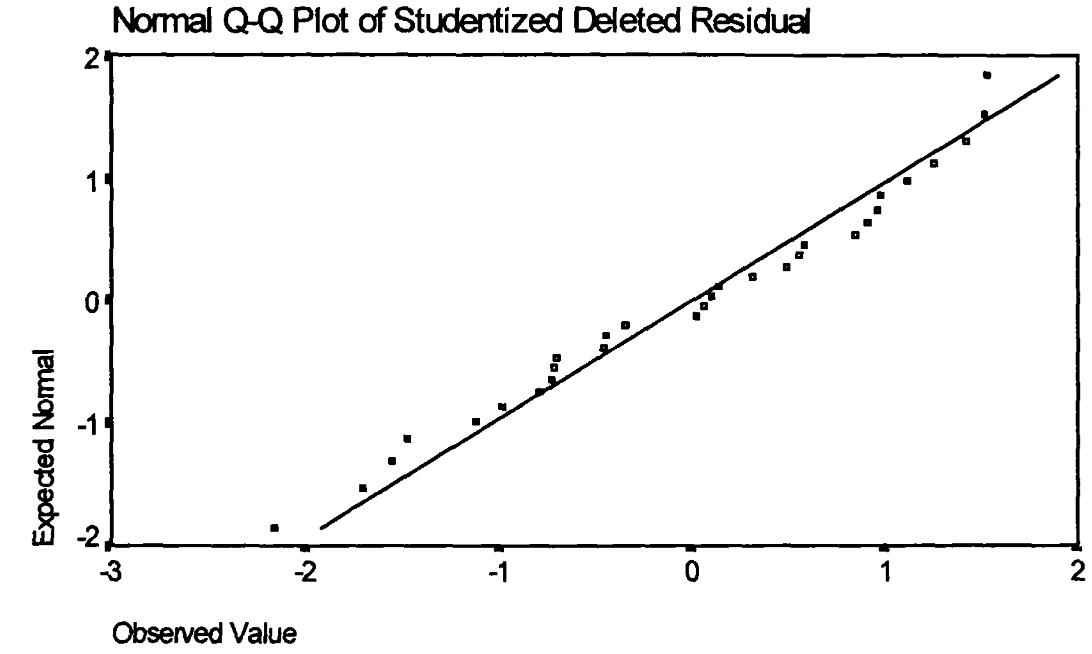


Figure 7.7.2 Studentised deleted residual/ expected normal plot for the trabecular base-line density data and LAXS data, females.

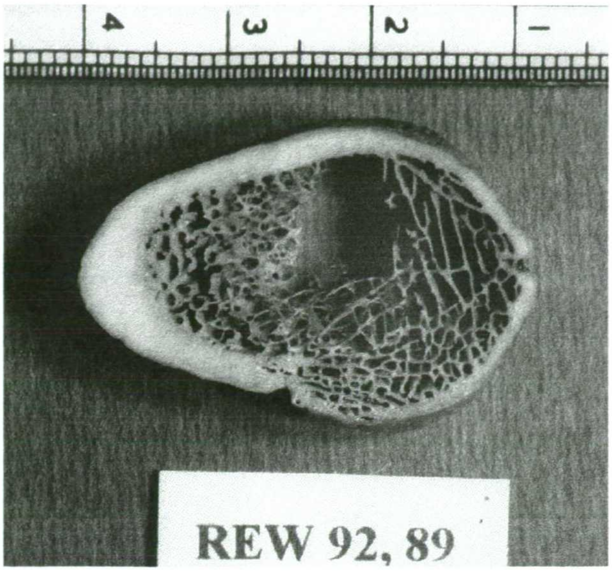
Two types of correlation coefficient were used for the statistical analysis; the Pearson correlation coefficient and the Spearman rank correlation coefficient. The Pearson correlation coefficient is parametric and calculates the coefficient from the actual data values. The Spearman rank correlation coefficient is non-parametric and replaces the actual data values with rank. The Pearson correlation coefficient is more 'powerful' and was therefore used in preference to the Spearman rank correlation coefficient. However, the Spearman rank correlation coefficient can be used on data ranked in categories and does not require the assumption of normality. For this reason, the Spearman rank correlation has been used for correlations of base-line density with age and also with the Singh index. It was also used when the K-S (Lilliefors) test showed that the assumption of normality was not met conclusively. In the case of correlation between estimated age at death and base-line density, the age category 15-25 years was excluded from the correlation. Base-line density showed a peak in the age category 26-35 years. This was justified because the object of the correlation was to examine the pattern of decline of bone mineral density after the attainment of peak density.

In a number of cases when the relationship between two variables was examined outliers were observed. These data were checked and in all cases found to be correct. For a selection of analyses the outliers were removed in order to see if this altered the observed relationship (for example Figures 8.3.5, 8.3.8, 10.5.3, 10.8.2). In all cases the removal of the outlier/s had little effect on the observed relationship, and therefore this process was not repeated for all possible outliers.

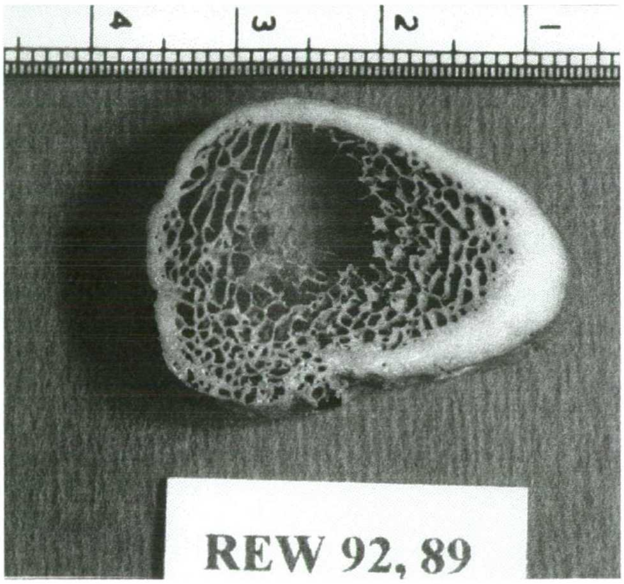
7.8 Illustrations of Sample Slices

A selection of sample slices obtained from all four skeletal elements (femoral neck, vertebral body, radius and iliac crest) used in the present study are illustrated. Figure 7.8.1 to Figure 7.8.3 are of sample slices taken from the femoral neck. A selection of sample slices taken from the fourth lumbar vertebral body are shown in Figure 7.8.4 to Figure 7.8.9. Figure 7.8.10 to Figure 7.8.12 are of sample slices taken from the radius, and Figure 7.8.13 to Figure 7.8.15 are of sample slices taken from the iliac crest. The results obtained from the various investigative techniques applied to the samples are shown in tables below. For each bone type pictures for illustration were selected from samples with a range of differing results.

7.8.1 Femoral Neck



a)



b)

Figure 7.8.1 Femur number 89 (Redcross Way). Both sides of the sample slice are illustrated to show the variation in slice area, cortical area and cortical thickness over 5mm.

REW 89 Female, Age Category 26-35 Years	
Whole bone base-line density	0.8124 (g cm^{-3})
Trabecular bone base-line density	0.2212 (g cm^{-3})
DEXA data	0.1845 (g cm^{-2})
LAXS data	236362 (photon counts)
Whole bone optical densitometry	6.637 (mm equiv. Al. th.)
Bone slice optical densitometry	3.55 (mm equiv. Al. th.)
Cortical thickness	0.1771 (cm)
Cortical index	19.9266
Cortical area	1.269 (cm^{-2})
Singh index	4

Table 7.8.1 Data obtained for femur REW 89 from each of the techniques used.

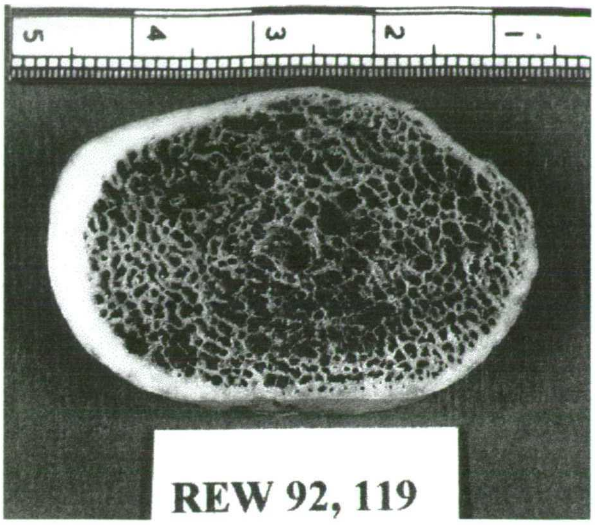


Figure 7.8.2 Sample slice obtained from femur 119 (Redcross Way)

REW 119 Male, Age Category 46-55 Years	
Whole bone base-line density	0.5419 (g cm^{-3})
Trabecular bone base-line density	0.2275 (g cm^{-3})
DEXA data	0.0840 (g cm^{-2})
LAXS data	159825 (photon counts)
Whole bone optical densitometry	6.361 (mm equiv. Al. th.)
Bone slice optical densitometry	0.5916 (mm equiv. Al. th.)
Cortical thickness	0.1028 (cm)
Cortical index	6.9075
Cortical area	1.352 (cm^{-2})
Singh index	2

Table 7.8.2 Data obtained for femur REW 119 from each of the techniques used.

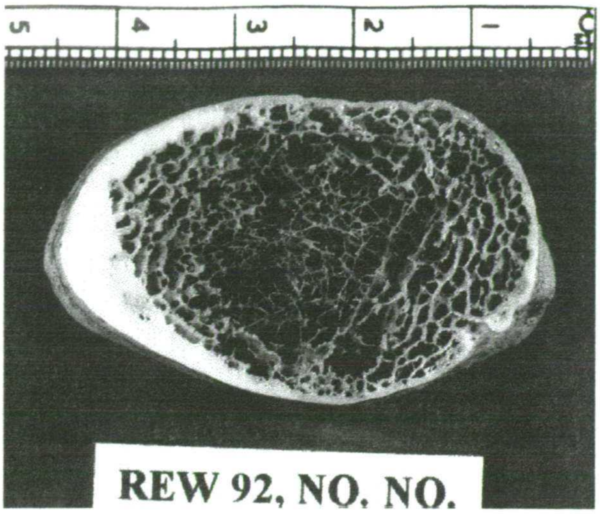


Figure 7.8.3 Sample slice obtained from femur no number (Redcross Way)

REW No Number Male, Age Category 46-55 Years	
Whole bone base-line density	0.4170 (g cm^{-3})
Trabecular bone base-line density	0.0683 (g cm^{-3})
DEXA data	0 (g cm^{-2})
LAXS data	408450 (photon counts)
Whole bone optical densitometry	3.175 (mm equiv. Al. th.)
Bone slice optical densitometry	0.1840 (mm equiv. Al. th.)
Cortical thickness	0.1483 (cm)
Cortical index	7.0483
Cortical area	1.766 (cm^{-2})
Singh index	3

Table 7.8.3 Data obtained for femur REW no number from each of the techniques used.

7.8.2 Vertebral Body

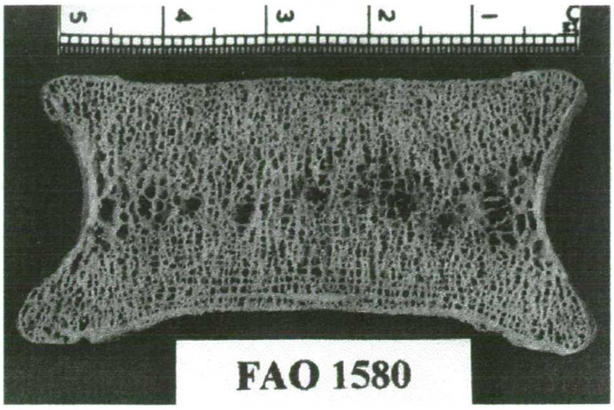


Figure 7.8.4 Sample slice obtained from vertebra FAO 1580 (Farringdon Street)

FAO 1580 Male, Age Category 26-35 Years	
Whole bone base-line density	0.5055 (g cm^{-3})
Trabecular bone base-line density	- (g cm^{-3})
Mean trabecular length	0.2865 cm
Trabecular length standard deviation	0.1344

Table 7.8.4 Data obtained for vertebra FAO 1580 from each of the techniques used.

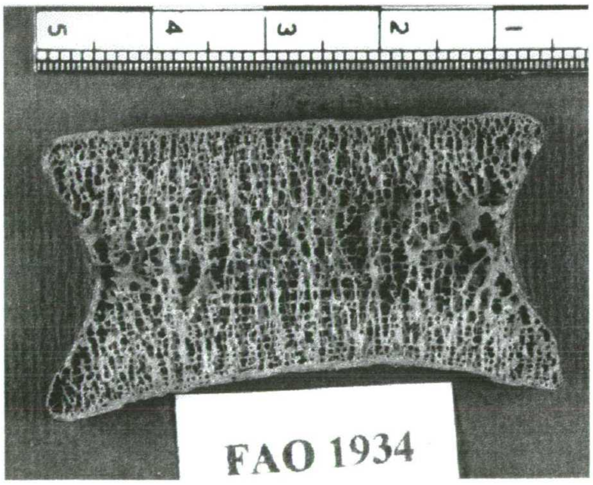


Figure 7.8.5 Sample slice obtained from vertebra FAO 1934 (Farringdon Street)

FAO 1934 Female, Age Category 26-35 Years	
Whole bone base-line density	0.2848 (g cm^{-3})
Trabecular bone base-line density	0.2770 (g cm^{-3})
Mean trabecular length	0.6862 cm
Trabecular length standard deviation	0.5699

Table 7.8.5 Data obtained for vertebra FAO 1934 from each of the techniques used.

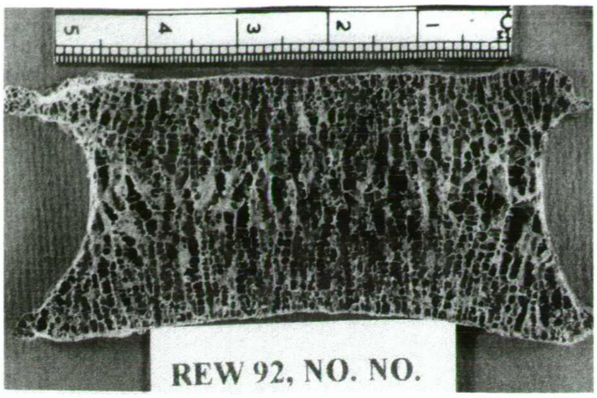


Figure 7.8.6 Sample slice obtained from vertebra REW no number (Redcross Way)

REW No Number Male, Age Category 56+ Years	
Whole bone base-line density	0.2040 (g cm^{-3})
Trabecular bone base-line density	0.1324 (g cm^{-3})
Mean trabecular length	0.8956 cm
Trabecular length standard deviation	0.3318

Table 7.8.6 Data obtained for vertebra REW no number from each of the techniques used.

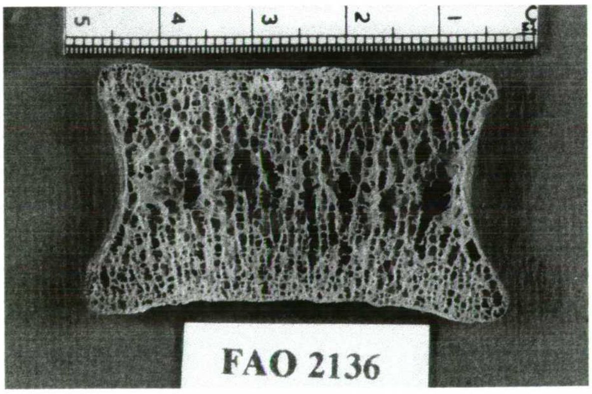


Figure 7.8.7 Sample slice obtained from vertebra FAO 2136 (Farringdon Street)

FAO 2163 Female, Age Category 36-45 Years	
Whole bone base-line density	0.2518 (g cm^{-3})
Trabecular bone base-line density	- (g cm^{-3})
Mean trabecular length	0.8227 cm
Trabecular length standard deviation	0.5238

Table 7.8.7 Data obtained for vertebra FAO 2136 from each of the techniques used.

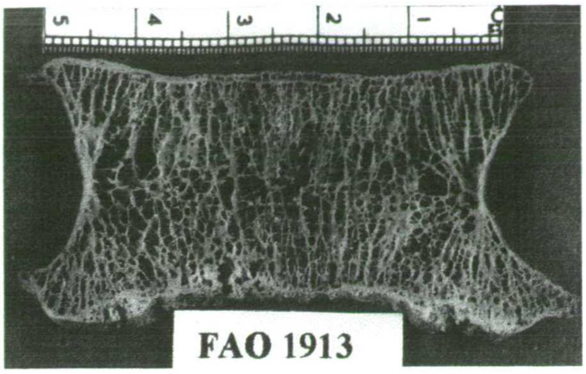


Figure 7.8.8 Sample slice obtained from vertebra FAO 1930 (Farringdon Street).

FAO 1913 Female, Age Category 56+ Years	
Whole bone base-line density	0.2189 (g cm^{-3})
Trabecular bone base-line density	0.2217 (g cm^{-3})
Mean trabecular length	1.3887 cm
Trabecular length standard deviation	0.7767

Table 7.8.8 Data obtained for vertebra FAO 1913 from each of the techniques used.

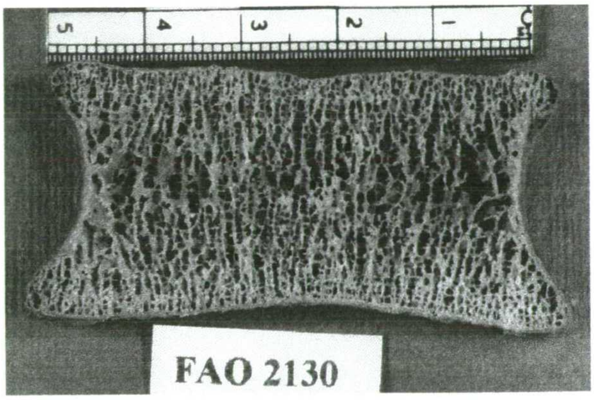


Figure 7.8.9 Sample slice obtained from vertebra FAO 2130 (Farringdon Street).

FAO 2130 Male, Age Category 36-45 Years	
Whole bone base-line density	0.3063 (g cm^{-3})
Trabecular bone base-line density	0.2518 (g cm^{-3})
Mean trabecular length	0.5373 cm
Trabecular length standard deviation	0.1752

Table 7.8.9 Data obtained for vertebra FAO 2130 from each of the techniques used.

7.8.3 Radius

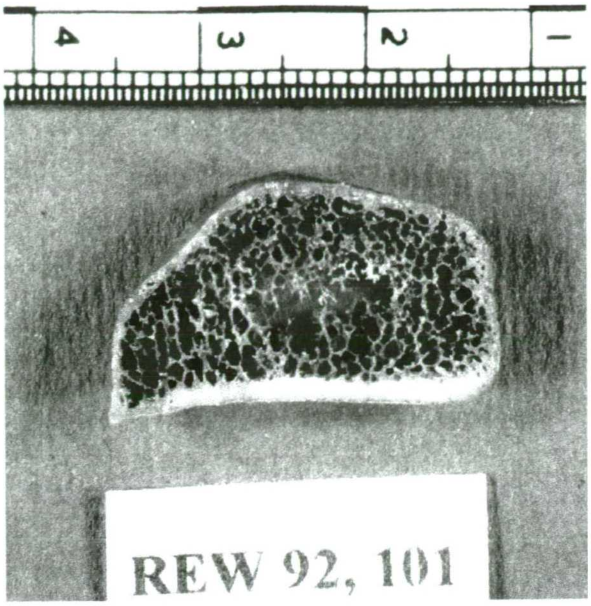


Figure 7.8.10 Sample slice obtained from radius REW 101 (Redcross Way).

REW 101 Female, Age category 36-45 Years	
Whole bone base-line density	0.5809 (g cm^{-3})
DEXA density	0.0093 (g cm^{-2})
Whole bone optical densitometry	6.583 (mm equiv. Al. th.)
Bone slice optical densitometry	0.802 (mm equiv. Al. th.)

Table 7.8.10 Data obtained for radius REW 101 from each of the techniques used.

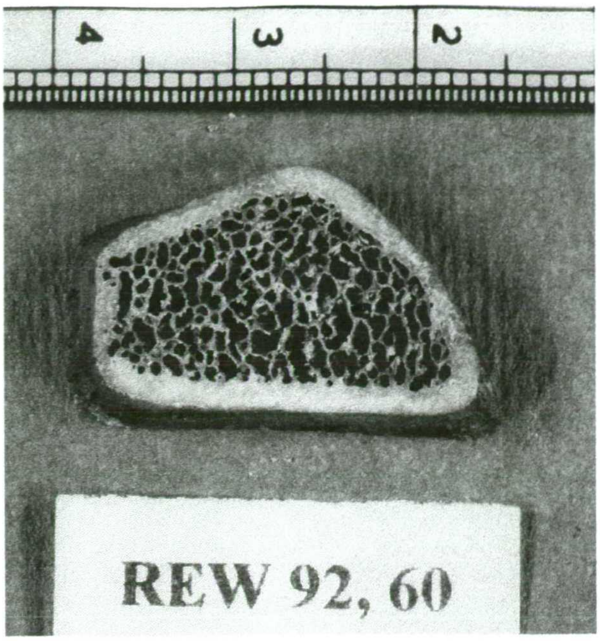


Figure 7.8.11 Sample slice obtained from radius REW 60 (Redcross Way).

REW 60 Male, Age category 46+ Years	
Whole bone base-line density	0.8149 (g cm^{-3})
DEXA density	0.1425 (g cm^{-2})
Whole bone optical densitometry	10.825 (mm equiv. Al. th.)
Bone slice optical densitometry	1.187 (mm equiv. Al. th.)

Table 7.8.11 Data obtained for radius REW 60 from each of the techniques used.

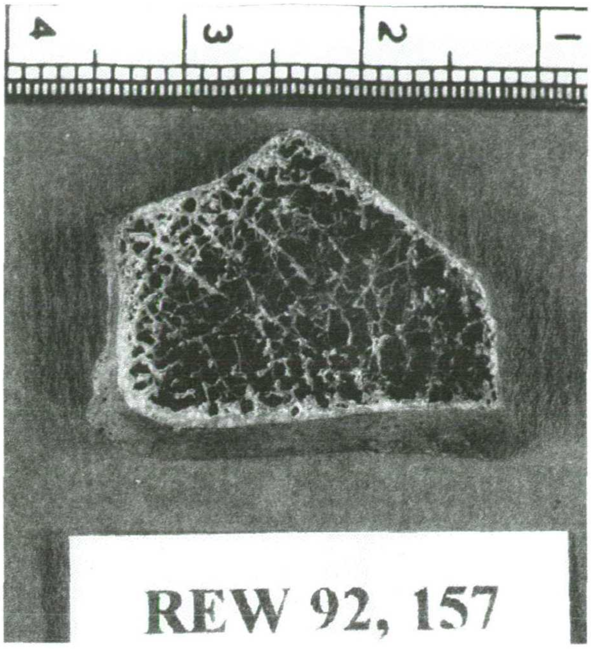


Figure 7.8.12 Sample slice obtained from radius REW 157 (Redcross Way).

REW 157 Female, Age Category 56+ Years	
Whole bone base-line density	0.3270 (g cm^{-3})
DEXA density	0 (g cm^{-2})
Whole bone optical densitometry	2.405 (mm equiv. Al. th.)
Bone slice optical densitometry	- (mm equiv. Al. th.)

Table 7.8.12 Data obtained for radius REW 157 from each of the techniques used.

7.8.4 Iliac Crest

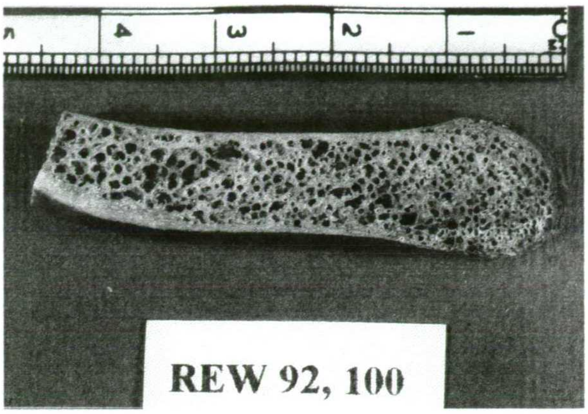


Figure 7.8.13 Sample slice obtained from iliac crest REW 100 (Redcross Way).

Female, Age Category 46-55 Years	
Whole bone base-line density	0.6810 (g cm^{-3})
DEXA density	0.0960 (g cm^{-2})
Whole bone optical densitometry	3.069 (mm equiv. Al. th.)
Bone slice optical densitometry	1.558 (mm equiv. Al. th.)

Table 7.8.13 Data obtained for iliac crest REW 100 from each of the techniques used.

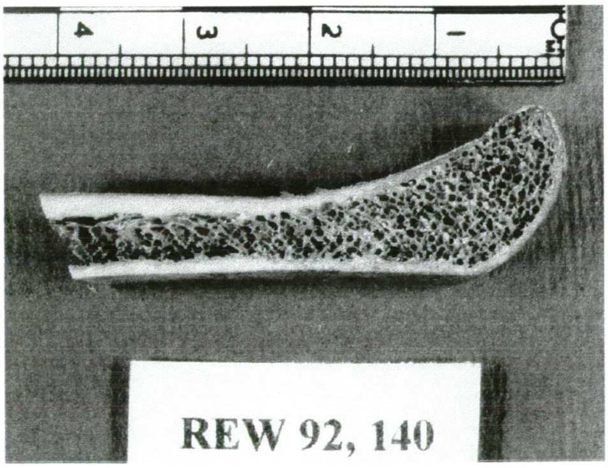


Figure 7.8.14 Sample slice obtained from iliac crest REW 140 (Redcross Way).

Female, Age Category 26-35 Years	
Whole bone base-line density	0.8355 (g cm^{-3})
DEXA density	0.0825 (g cm^{-2})
Whole bone optical densitometry	2.965 (mm equiv. Al. th.)
Bone slice optical densitometry	2.201 (mm equiv. Al. th.)

Table 7.8.14 Data obtained for iliac crest REW 140 from each of the techniques used.

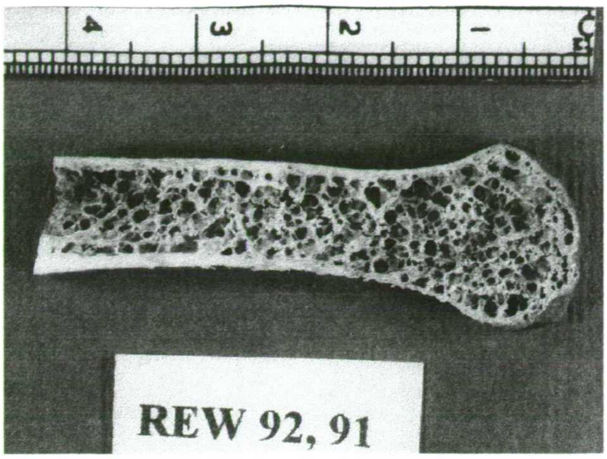


Figure 7.8.15 Sample slice obtained from iliac crest REW 91 (Redcross Way).

Male, Age Category 56+ Years	
Whole bone base-line density	0.4401 (g cm^{-3})
DEXA density	0.0595 (g cm^{-2})
Whole bone optical densitometry	4.331 (mm equiv. Al. th.)
Bone slice optical densitometry	- (mm equiv. Al. th.)

Table 7.8.15 Data obtained for iliac crest REW 91 from each of the techniques used.

8. Results of the Determination of Bone Density

8.1 Introduction

This chapter is divided into sections detailing the results of each type of bone density analysis performed on the sample material. The main headings under which the results are presented are as follows.

8.2 Base-line density
8.3 Optical densitometry
8.4 Dual Energy X-ray Absorptiometry (DEXA)
8.5 Low Angle X-ray Scattering (LAXS)

Density is a frequently used measure of bone loss with age (Sections 2.3 and 2.4), and the relationship of age/sex and bone mineral density (BMD) is examined in detail Section 8.2. In this study BMD is defined as the physical density of the minerals that make up the bone. The relationship between whole and trabecular bone density, and density in various skeletal elements was also investigated.

Sections 8.3 - 8.5 detail results obtained from different X-ray techniques for the assessment of bone density. In Redcross Way whole bone density was calculated for all four sampled bones, and trabecular density was calculated for the femoral neck and vertebral body. For Farringdon Street whole bone density was calculated for all vertebral body samples, and trabecular bone density for a sample of 92. The results from each of these techniques are compared to base-line density for both whole and trabecular bone to determine the reliability of each technique.

8.2 Base-line Bone Density

The base-line density is the direct measurement (Section 7.3.1) of bone density. This direct measurement was performed for the whole bone and trabecular bone. The density of trabecular bone was determined for vertebral bodies and femoral necks. The results for the vertebral body are presented for the complete sample set and for a subsample. The complete sample set refers to all vertebral body slices from which data could be obtained from Redcross Way and Farringdon Street. The subsample was a selection of vertebral bodies which were randomly picked from material available from Redcross Way and Farringdon Street for stereometric analysis. A subsample was taken because there was insufficient time to apply stereometric analysis to all available material. Density results are presented for the complete sample set and the subsample to allow direct comparisons to be made between density and structural (stereometric) analysis of the trabeculae (Section 9.3). Illustrations in Section 7.8 show examples of the photographs which were used for the calculation of whole bone base-line density, and in the case of femoral necks and vertebral bodies trabecular bone density.

The relationship between density and age/sex is examined in detail in this section because density is a frequently used measure of bone loss with age. Detailed plots of all individual measurements obtained from the Redcross Way and Farringdon Street material are given for the vertebral body (Figure 8.2.1 and Figure 8.2.3). These plots include an horizontal marker indicating the mean measurement and a vertical marker indicating the range of the measurements for an age/sex category. Only material from Redcross Way was available for the other skeletal elements examined. These were the femoral neck, radius and iliac crest (Section 8.2.5). For these skeletal elements a simpler form of plot is given as sample numbers were small for Redcross Way.

8.2.1 Vertebral Body, Whole Bone Density - Complete Sample Set

The whole bone density data was obtained from bone slices using the methods detailed in Section 7.3. It was possible to obtain suitable slices for the calculation of whole bone density from 175 vertebral bodies. The number of samples obtained from each age/sex category are detailed in Table 8.2.1.

The results of the whole bone density analysis are plotted in Figure 8.2.1. Peak mean bone density for both males and females occurred in age category 26-35 years. Mean bone density for the females decreased consistently after the peak. In contrast, the males exhibited very little difference in mean bone density in the two older age categories, but the mean bone density for 46+ years was slightly higher than for 36-45 years. The range of densities for each age category became greater with advancing age, although the female age category 36-45 years had a much greater range of densities than all other groups due to several outliers with extremely high density.

Age/Sex Category	Number
< 25	9
m 26-35	17
f 26-35	24
m 36-45	26
f 36-45	18
m 46+	50
f 46+	31

Table 8.2.1 The number of individuals examined for whole bone density in each age/sex category for the complete sample set.

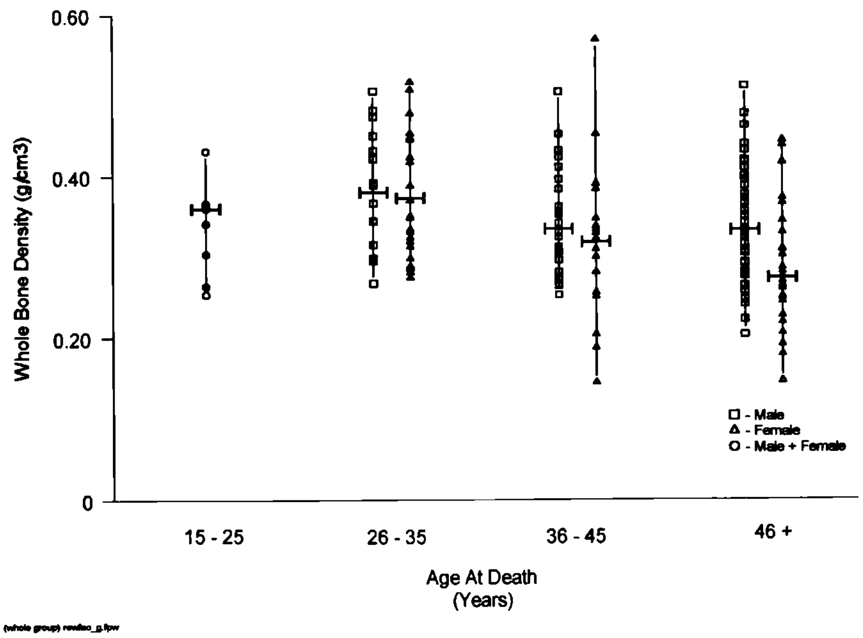


Figure 8.2.1 Whole bone density from each fourth lumbar vertebral body sampled for the complete sample set plotted against age/sex. The horizontal bars represent the mean value for each category. The vertical bars mark the range of densities.

The Spearman rank correlation coefficient between sex/age and whole bone density are given below.

<u>Males</u>

Rank correlation coefficient (Spearman) r = - 0.076, significance = 0.470 (individuals under the age of 26 were omitted, see Section 7.7).

<u>Females</u>

Rank correlation coefficient (Spearman) $r = -0.34$, significance = 0.007 (individuals under the age of 26 were omitted, see Section 7.7).

There was a very weak negative correlation, which was not found to be significant between estimated age at death in the males and whole bone density. For the females there was a low negative correlation which was highly significant.

Complete Sample Set								
Whole Density								
	15-25	f 26-35	f 36-45	f 46+		m 26-35	m 36-45	m 46+
15-25	*							
f 26-35	*0.5661*	*						
f 36-45	*0.0638*	0.0142	*					
f46+	*0.0428*	0.0004	0.2270	*				
m 26-35	*0.8252*	0.7587	0.0295	0.0001		*		
m 36-45	*0.2170*	0.2361	0.2228	0.0012		0.1607	*	
m46+	*0.3812*	0.0388	0.4552	0.0027		0.0300	0.4031	*

Table 8.2.2 T-tests for levels of significance of whole bone density data between age categories for the complete sample set. Results placed in italics are for age categories that did not have a normal data distribution and were therefore unsuitable for this test. In these cases the Mann-Witney U test was used. Shaded cells are statistically significant.

Results of the statistical analyses for the whole bone density data of the complete sample set are given in Table 8.2.2. The female age category 46+ years is different at the highly significant level from the male age category 26-35 years; at the very significant level from the male age categories 36-45 years and 46+ years; at the significant level from the mixed sex age category 15-25 years. The male category 46+ years and the female age category 36-45 years are different at the significant level. The female category 26-35 years and the female age category 36-45 years are also different at the significant level.

8.2.2 Subsample, Whole Bone Density

Seventy five samples were randomly chosen from the complete sample set for stereometric analysis (Section 7.5.3). The density data in these samples were investigated separately to allow comparison with the stereometric data. The number of samples obtained from each age/sex category are detailed in Table 8.2.3. Data from the subsample were divided into a further age category to allow more detailed analysis (Section 6.2.8).

Age/Sex Category	Number
m+f < 25	6
m 26-35	9
f 26-35	10
m 36-45	10
f 36-45	9
m 46-55	12
f 46-55	7
m 56+	6
f 56+	6

Table 8.2.3 The number of individuals examined for whole bone density in each age/sex category for the subsample.

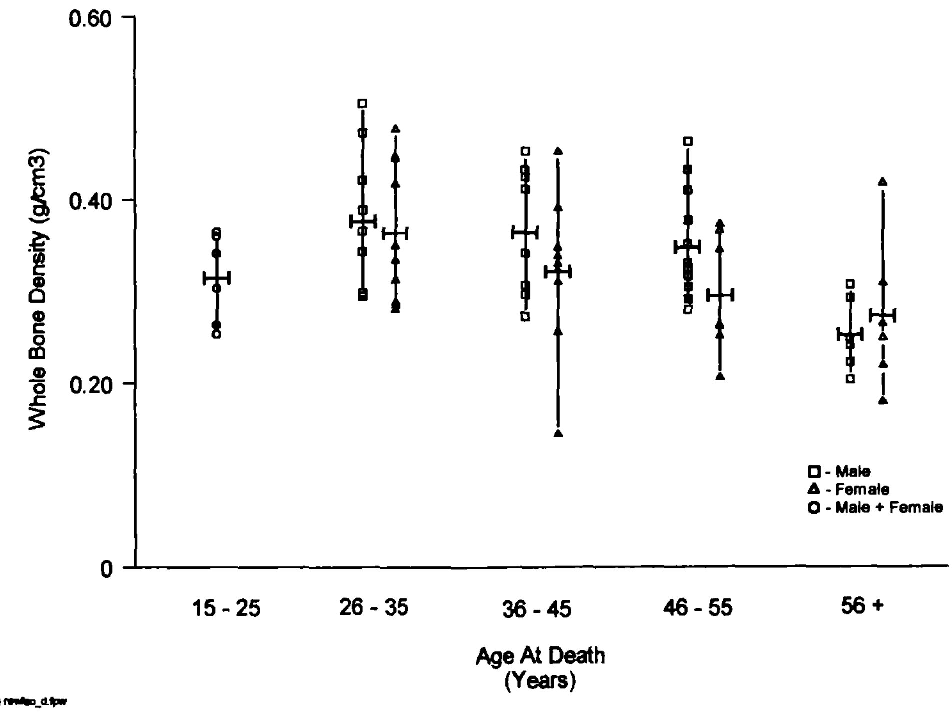


Figure 8.2.2 Whole bone density for each vertebral body plotted against age/sex for the subsample. The horizontal bars represent the mean value for each category. The vertical bars mark the range of densities.

The subsample (Figure 8.2.2) shows a similar pattern to that seen in the complete sample set (Figure 8.2.1). However, the additional category 56+ years shows a sharp decline for the males. The male mean in this category is lower than the female mean, but is undoubtedly caused by an outlier with a very high density value within the female 56+ age category.

The Spearman rank correlation coefficient between sex/age and whole bone density are given below.

Males

Rank correlation coefficient (Spearman) r = -0.42, significance = 0.024 (individuals under the age of 26 were omitted, see Section 7.7).

Females

Rank correlation coefficient (Spearman) r = -0.38, significance = 0.019 (individuals under the age of 26 were omitted, see Section 7.7).

There was a low negative correlation in the subsample of males which was significant. The correlation in the female sample was slightly lower but was also significant.

Results of the statistical analyses for the whole bone density data from the subsample are given in Table 8.2.4. As in the whole sample most differences were observed between the youngest and oldest age categories. The male age category 56+ years was different at the very significant level from female age category 26-35 years, and the male age categories 26-35 years, 36-45 years and 46-55 years. The male age category 56+ years was also observed to be different at the significant level from the mixed sex age category 15-25 years. The female age category 46-55 years and the male age category 36-45 years were different at the significant level. The female age category 56+ years and the male age category 26-35 years were also different at the significant level.

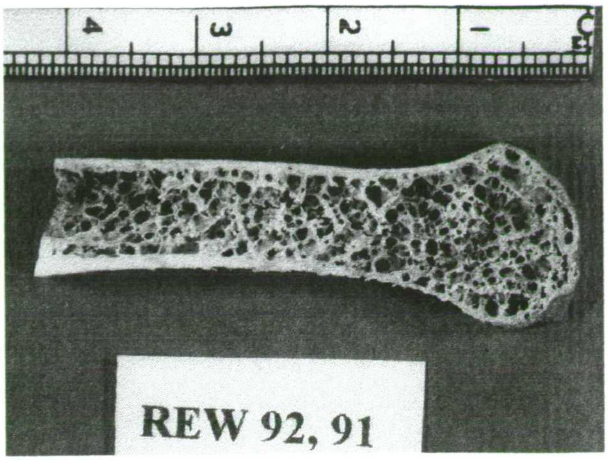


Figure 7.8.15 Sample slice obtained from iliac crest REW 91 (Redcross Way).

Male, Age Category 56+ Years	
Whole bone base-line density	0.4401 (g cm^{-3})
DEXA density	0.0595 (g cm^{-2})
Whole bone optical densitometry	4.331 (mm equiv. Al. th.)
Bone slice optical densitometry	- (mm equiv. Al. th.)

Table 7.8.15 Data obtained for iliac crest REW 91 from each of the techniques used.

Subsample										
Whole Density										
	15-25	f 26-35	f 36-45	f 46-55	f 56+		m 26-35	m 36-45	m 46-55	m 56+
15-25	*									
f 26-35	0.1400	*								
f 36-45	0.9900	0.1900	*							
f 46-55	*0.5728*	*0.0831*	*0.6334*	*						
f 56+	0.3300	0.0590	0.3600	*0.6620*	*					
m 26-35	0.0830	0.7200	0.1200	*0.0721*	0.0370		*			
m 36-45	0.1300	0.9800	0.1800	*0.0464*	0.0540		0.7400	*		
m 46-55	0.2200	0.6100	0.3100	*0.0574*	0.0910		0.3800	0.5900	*	
m 56+	0.0400	0.0022	0.0680	*0.2844*	0.6000		0.0017	0.0017	0.0013	*

Table 8.2.4 T-tests for levels of significance of whole bone density data between age categories for the sub sample. Results placed in italics are for age categories that did not have a normal data distribution and were therefore unsuitable for this test. In these cases the Mann-Witney U test was used. The shaded cells are statistically significant at < 0.05.

8.2.3 Vertebral Body, Complete Sample Set - Trabecular Bone Density

The trabecular bone density data were obtained from the bone slices using the methods detailed in Section 7.3 for material from Redcross Way and Farringdon Street. Density was calculated for 93 vertebral bodies. The number of samples obtained from each age/sex category are detailed in Table 8.2.5.

Age/Sex Category	Number
< 25	4
m 26-35	10
f 26-35	19
m 36-45	14
f 36-45	9
m 46+	24
f 46+	13

Table 8.2.5 The number of individuals examined for trabecular bone density in each age/sex category for the complete sample set.

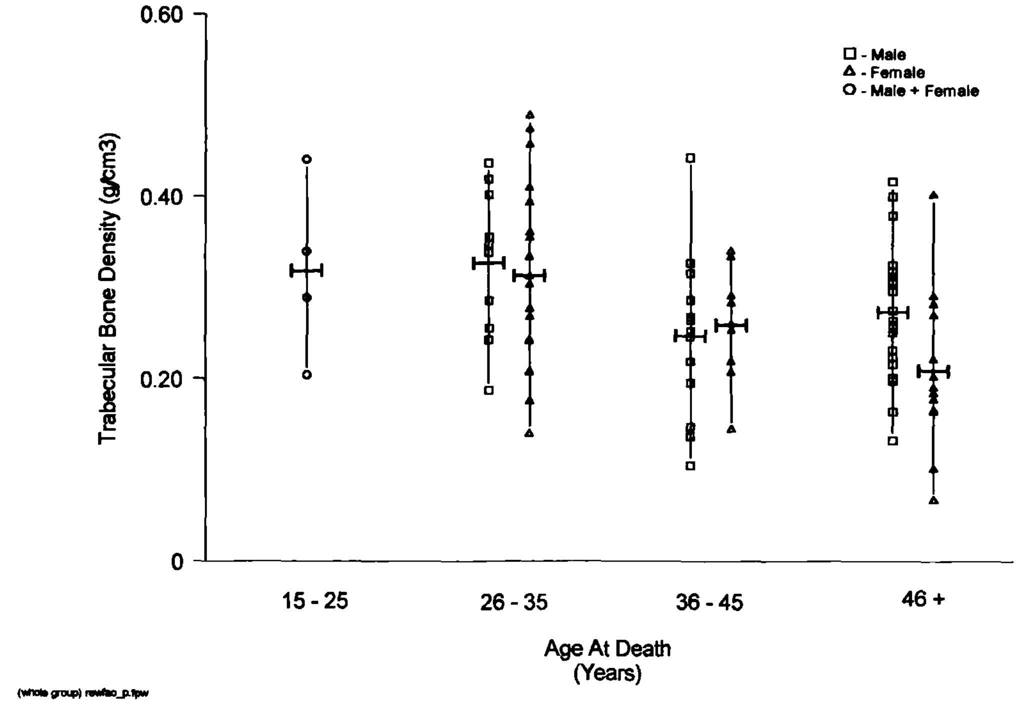


Figure 8.2.3 Trabecular bone density from the vertebral body for each individual, plotted against age/sex for the complete sample set. The horizontal bars represent the mean value for each category. The vertical bars mark the range of densities.

As in the whole bone density analysis (Sections 8.2.1, 8.2.2), peak density for males lay in the category 26-35 years. However, the females in this category had a slightly lower bone density than that recorded for individuals aged 15-26. Overall, there was a decline in trabecular bone density with age for both sexes. In all groups except the category 36-45 years the males had a higher trabecular bone density than females of the same age. The mean density of the male category 36-45 years is unusually low in comparison to the whole bone density data, and would be lower but for the presence of an outlier.

The Spearman rank correlation coefficient between sex/age and trabecular bone density are given below.

Males

Rank correlation coefficient (Spearman) r = - 0.069, significance = 0.628 (individuals under the age of 26 were omitted, see Section 7.7).

Females

Rank correlation coefficient (Spearman) r = - 0.38, significance = 0.027 (individuals under the age of 26 were omitted, see Section 7.7).

In the sample of males there was a very weak negative correlation which was not significant between estimated age at death and vertebral trabecular density. For the females the negative correlation was extremely weak but was significant at the 5% level.

Complete Sample Set								
Trabecular Density								
	15-25	f 26-35	f 36-45	f 46+		m 26-35	m 36-45	m 46+
15-25	*							
f 26-35	*0.8375*	*						
f 36-45	*0.6095*	0.0612	*					
f 46+	*0.0790*	0.0043	0.1629	*				
m 26-35	*1.0000*	0.6914	0.0383	0.0034		*		
m 36-45	*0.0582*	0.0537	0.8270	0.2654		0.0330	*	
m 46+	*0.4290*	0.1577	0.4206	0.0317		0.1451	0.3401	*

Table 8.2.6 T-tests for levels of significance of trabecular bone density data between age categories for the complete sample set. Results placed in italics are for age categories that did not have a normal data distribution and were therefore unsuitable for this test. In these cases the Mann-Witney U test was used. The shaded cells are statistically significant at < 0.05.

Results of the statistical analyses for the trabecular bone density data of the complete sample set are given in Table 8.2.6. The female age category 46+ years was different at the very significant level from the female age category 26-35 years and the male age category 26-35 years, and different at the significant level from the male age category 46+ years. The male age category 26-35 years was different at the significant level from the female age category 26-35 years and the male age category 26-35 years.

8.2.4 Subsample, Trabecular Bone Density.

The trabecular bone density data were obtained from the bone slices using the methods detailed in Section 7.3. Density was calculated for 46 vertebral bodies. The number of samples obtained from each age/sex category are detailed in Table 8.2.7.

Age/Sex Category	Number
m+f < 25	3
m 26-35	5
f 26-35	8
m 36-45	7
f 36-45	5
m 46-55	8
f 46-55	3
m 56+	3
f 56+	4

Table 8.2.7 The number of individuals in each age/sex category for the subsample examined for trabecular bone density.

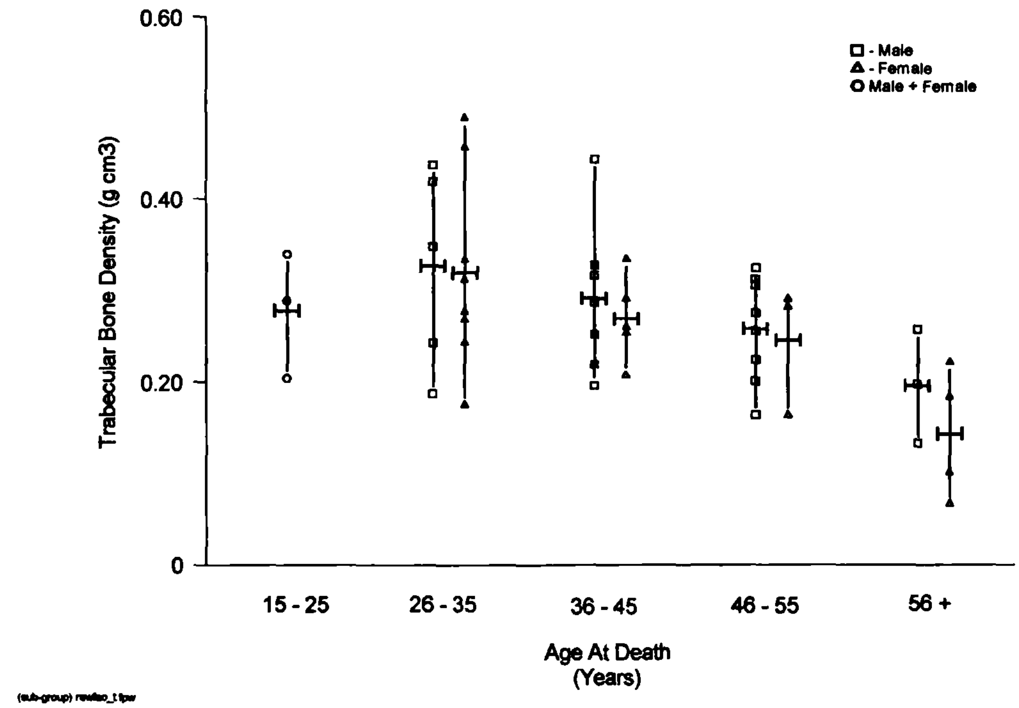


Figure 8.2.4 Trabecular bone density from the vertebral body plotted against age/sex for each individual in the subsample. The horizontal bars represents the mean value for each category. The vertical bars mark the range of densities.

Peak bone density for both males and females occurred in the age categories 26-35 years with a gradual decline in older age categories (Figure 8.2.4). The lowest bone density was seen in the female age category 56+ years. Male age categories always had a slightly higher mean density than female categories of the same age. However, outliers such as the individual with the highest density in the male age category 36-45 years, undoubtedly increased the mean for this category.

The Spearman rank correlation coefficients between sex/age and trabecular bone density are given below.

Males

Correlation coefficient (Spearman) $r = -0.35$, significance = 0.160 (individuals under the age of 26 were omitted, see Section 7.7).

Females

Rank correlation coefficient (Spearman) $r = -0.50$, significance = 0.011 (individuals under the age of 26 were omitted, see Section 7.7).

In the males there was a low correlation between estimated age at death and the trabecular bone density, but this was not statistically significant. Females had a moderate correlation which was significant.

Subsample										
	15-25	f 26-35	f 36-45	f 46-55	f 56+		m 26-35	m 36-45	m 46-55	m 56+
15-25	*									
f 26-35	*1.0000*	*								
f 36-45	*1.0000*	0.1900	*							
f 46-55	*0.4000*	*0.3301*	*0.4127*	*						
f 56+	*0.1143*	0.0069	0.0252	*0.3429*	*					
m 26-35	*0.8571*	*1.0000*	*0.9048*	*0.3429*	*0.0571*		*			
m 36-45	*0.9048*	0.5800	0.3988	*0.3524*	0.0165		*1.0000*	*		
m 46-55	*0.6303*	0.1800	0.9801	*0.5697*	0.0389		*0.5697*	0.3896	*	
m 56+	*0.2000*	*0.1000*	*0.1429*	*0.6286*	*0.4000*		*0.1000*	*0.2619*	*0.1939*	*

Table 8.2.8 T-tests for levels of significance of trabecular bone density data between age categories for the subsample. Results placed in italics are for age categories that did not have a normal data distribution and were therefore unsuitable for this test. In these cases the Mann-Witney U test was used. The shaded cells are statistically significant at <0.05.

Results of the statistical analyses for the trabecular bone density data of the subsample are given in Table 8.2.8. There were very few age categories for which data was found to be normally distributed, probably because of the low sample numbers. The only age categories between which significant differences were observed were between females 56+ years and the categories females 26-35 years, males 36-45 years, and 46-55 years.

8.2.4.1 World Health Organisation Definition of Osteopenia and Osteoporosis

The World Health Organisation (WHO) Definition of osteoporosis and osteopenia is as follows.
Normal - a value of BMD or bone mineral content (BMC) within 1 SD of the young adult reference mean.
Low Bone Mass (osteopenia) - a value for BMD or BMC more than 1 SD below the young adult mean but less than 2.5 SD below this value.
Osteoporosis - a value for BMD or BMC 2.5 SD or more below the young adult mean. (WHO Geneva 1994).

Using the criteria set out by the WHO for the definition of low bone density (osteopenia) and osteoporosis the whole bone base-line density data obtained from the complete sample set was examined. Normal density was defined for males and females on the basis of data obtained from the age categories 26-35 years. The criteria used are set out in Table 8.2.9 and the results obtained in Table 8.2.10.

mean	0.3796941		0.372420833
sd	0.0728675		0.075826088
crt1	0.3068266		0.296594745
(m-1sd)			
crt2	0.1975253		0.182855613
(m-2.5sd)			

Table 8.2.9 Criteria calculated for the definition of osteopenia and osteoporosis in males and females based on the age category 26-35 years.

	Number of Samples	Normal	Osteopenia	Osteoporosis
Criteria		>0.3068	<0.3068 & >0.1973	<0.1973
M 36-45	26	16 (61.5%)	10 (38.5%)	0
M 46+	46	31 (67.4%)	15 (32.6%)	0
Criteria		>0.2966	<0.2966 & >0.1829	<0.1829
F 36-45	19	12 (63.2%)	6 (31.6%)	1 (5.2%)
F 46+	31	11 (35.4%)	18 (58%)	2 (6.6%)

Table 8.2.10 Number in sample for each age/sex category for which the WHO definition of osteopenia and osteoporosis could be applied. The percentage is the percent of those in each age/sex category which met the WHO criteria.

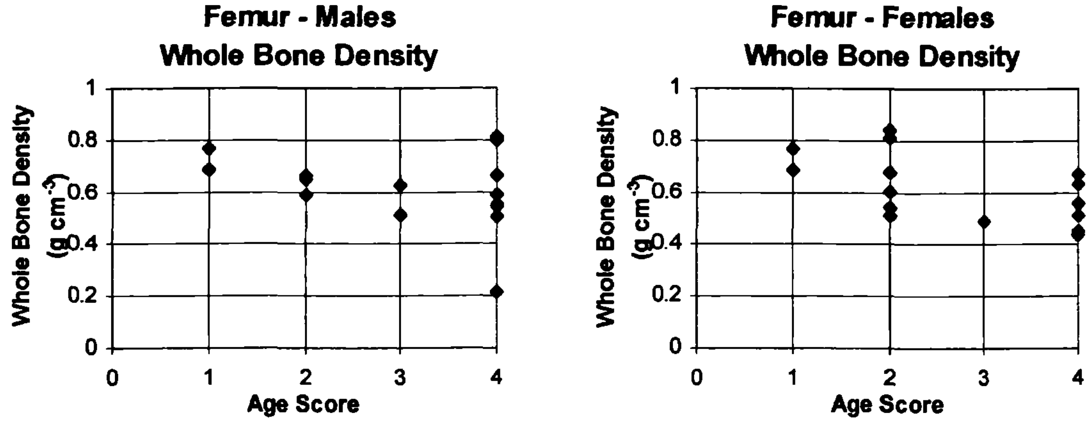
8.2.5 Relationship between Density and Age for Different Skeletal Elements

The relationship between the estimated age at death of individuals from which the sample material was obtained and the data obtained from the base-line density data are examined in this section. The skeletal elements examined are the femoral neck, radius and iliac crest obtained from Redcross Way. For all elements examined the numbers were not large enough for rigorous statistical analysis. Table 8.2.11 shows the number of individuals in each age/sex category for each skeletal element.

Age/Sex Category	Number			
	Whole Bone			Trabec. Bone
	Femoral Neck	Radius	Iliac Crest	Femoral Neck
<25	2	1	2	2
m26-35	3	3	3	3
f26-35	6	4	6	6
m36-45	2	2	2	1
f36-45	1	1	1	2
m46+	9	7	5	8
f46+	6	6	3	7
Total	29	24	22	29

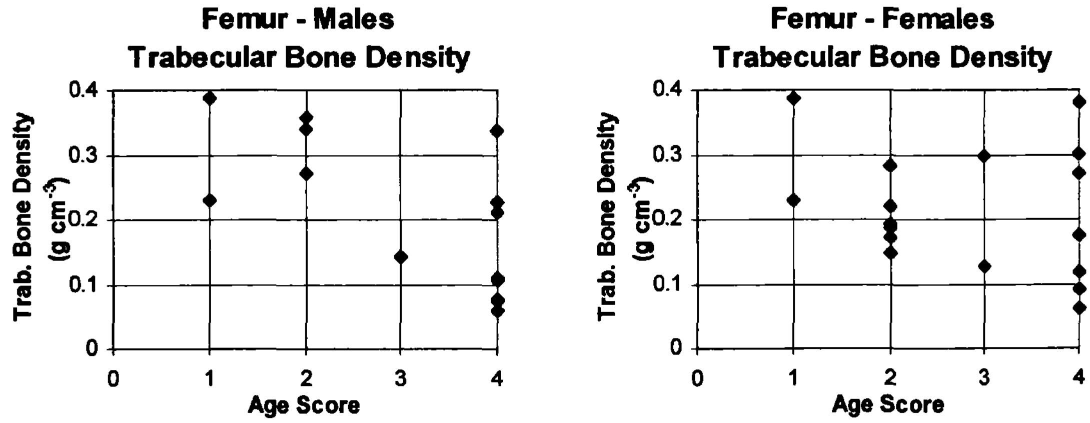
Table 8.2.11 The number of individuals in each age/sex category for the sample examined for base-line density.

Figure 8.2.5 to Figure 8.2.8 show the estimated age at death plotted against whole bone base-line density for the femoral neck, radius and iliac crest. Trabecular bone density is also plotted for the femoral neck Figure 8.2.6.



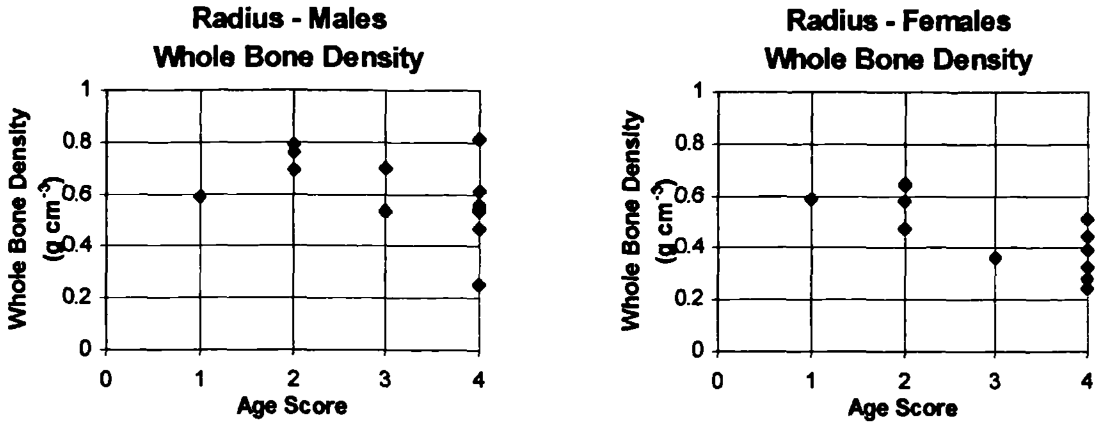
a) b)

Figure 8.2.5 Estimated age at death plotted against femoral neck whole bone density data for males a) and females b). Age score 1 = 15-25 years, 2 = 26-35 years, 3 = 36-45 years and 4 = 46+ years.



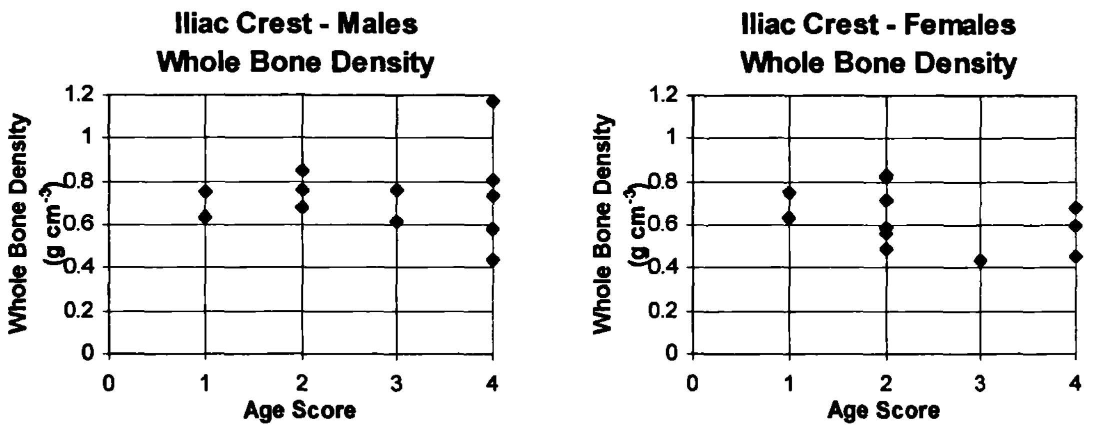
a) b)

Figure 8.2.6 Estimated age at death plotted against femoral neck trabecular bone density results for males a) and females b). Age score 1 = 15-25 years, 2 = 26-35 years, 3 = 36-45 years and 4 = 46+ years.



a) b)

Figure 8.2.7 Estimated age at death plotted against radius whole bone density results for males a) and females b). Age score 1 = 15-25 years, 2 = 26-35 years, 3 = 36-45 years and 4 = 46+ years.



a) b)

Figure 8.2.8 Estimated age at death plotted against iliac crest whole bone density results for males a) and females b). Age score 1 = 15-25 years, 2 = 26-35 years, 3 = 36-45 years and 4 = 46+ years.

It is difficult to analyse these plots objectively because of the limited number of data points. Most weight was given to those trends between categories with a relatively large number of data points.

There appeared to a decrease in density between age category 26-35 years and 46+ years for female femoral neck whole bone density, male femoral neck trabecular bone density, male and female radius whole bone density, and female iliac crest whole bone density. However, in all these cases there were only one or two data points in the age category 36-45 years. No other clear trends were apparent.

It should be noted that the pattern in these plots could be different if sample numbers were greater.

8.2.6 Relationship Between Whole and Trabecular Bone Density

Bone loss within the trabecular region, leading to structural deterioration, plays the most significant role in determining the likelihood of an individual sustaining an osteoporosis-related fracture (Section 2.3). Most of the non-invasive diagnostic techniques available can only produce results which relate to the whole bone. Therefore in the present study the relationship between whole and trabecular bone density was examined by comparing measurements of base-line density of the whole and trabecular bone for the vertebral bodies and femoral neck (Figure 8.2.9 and Figure 8.2.10).

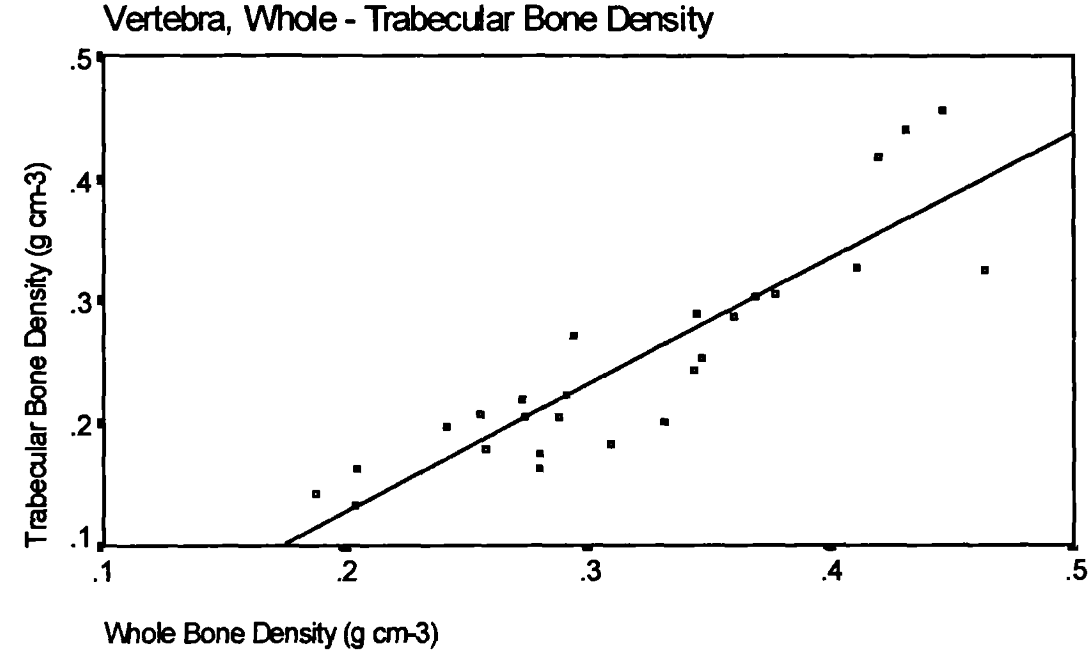


Figure 8.2.9 Whole bone density plotted against trabecular bone density measurements of the vertebrae. Rank correlation coefficient (Spearman) $r = 0.88$, significance, < 0.0001.

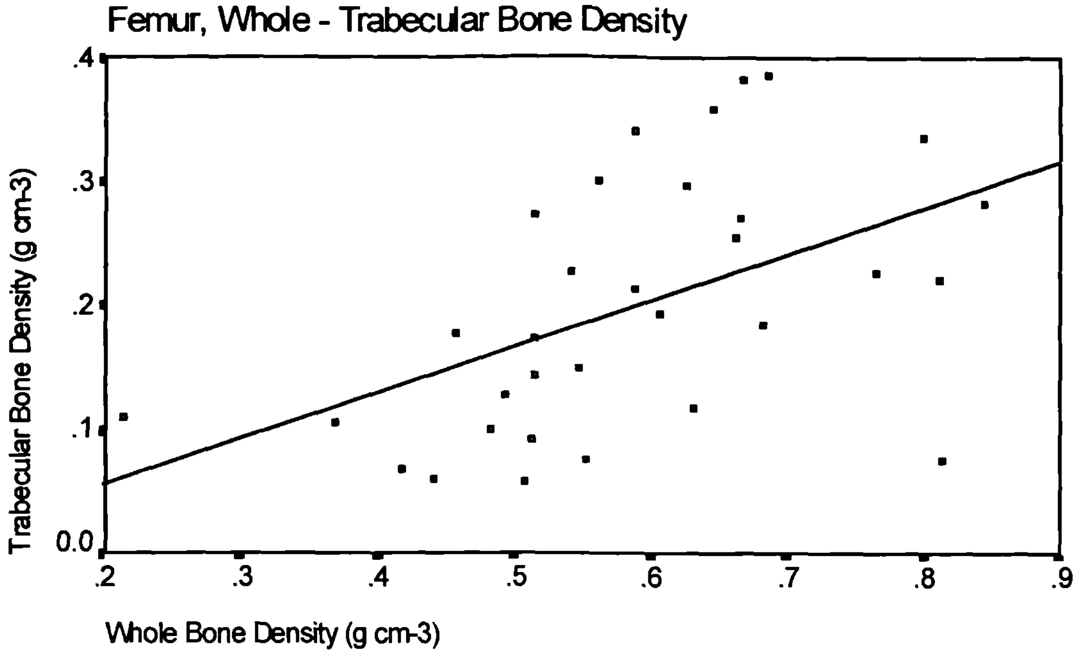


Figure 8.2.10 Whole bone density plotted against trabecular bone density measurements of the femora. Correlation coefficient (Pearson) r = 0.51, p = 0.003. K-S (Lilliefors) p > 0.2000.

There was a strong positive correlation between whole and trabecular bone density in the vertebral body. For the females there was a moderate but significant positive correlation between the two sets of data.

8.2.7 Relationship of Density between Different Skeletal Elements.

Several studies have investigated the relationship of bone loss from different parts of the skeleton (Mazess *et al.* 1988, Riggs *et al.* 1982, Wright *et al.* 1990). However, work to date has mainly been limited to clinical in *vivo* studies. In a few instances, it has been possible to study more than one bone element in archaeological material, but the relationship of bone loss at different skeletal areas has not been examined. The lack of such a study in archaeological material is probably due to two main reasons:

a) a study including statistically sufficient sample numbers would be extremely time consuming;
b) it is quite rare to have permission to sample archaeological bone material as extensively as in the present study.

Results from a study of the relationship of density between different skeletal elements should indicate if data produced from one skeletal area will allow assumptions to be made about the general processes of bone loss across the skeleton of the individual. This could be extremely valuable because of the constraints surrounding the sectioning of archaeological bone material.

The data obtained from the vertebral body was used as the dependent variable. There were several reasons for this choice:

a) the vertebrae are more frequently available to researchers working on archaeological bone;
b) there is often an understandable reluctance to allow any sectioning work on what is often archival or museum material. Permission will more frequently be given to section a vertebral body than a bone such as a femur because there are a number of vertebrae. Therefore the sectioning of one vertebra might not be considered as detrimental to the collection as a whole;
c) the 4th lumbar vertebrae have been shown to reliably produce better results (Section 8.5 and 8.2) than some of the other skeletal elements examined.

Although vertebrae from archaeological material are often slightly damaged, any damage is usually limited to the processes which are of little importance in the determination of age-dependent bone loss. It is rare that the vertebral body is so badly damaged that it is unusable. For this to happen, overall preservation has to be extremely poor.

Figure 8.2.11 to Figure 8.2.14 show the density of the vertebral body plotted against the density for other skeletal elements.

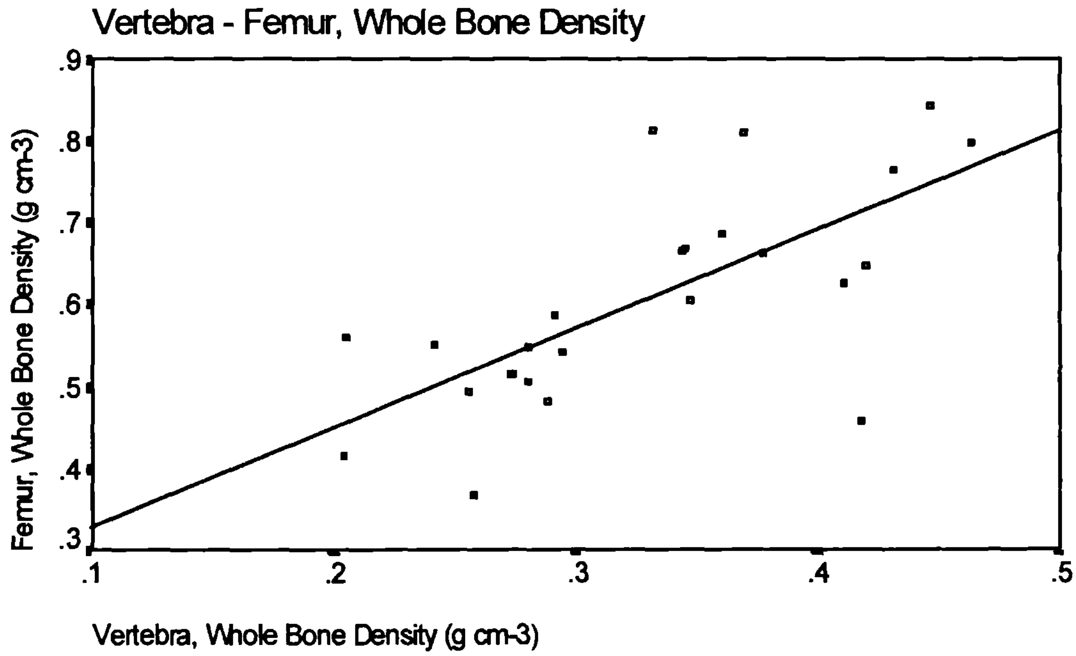


Figure 8.2.11 Vertebral body whole bone density plotted against femoral neck whole bone density. Correlation coefficient (Pearson) $r = 0.70$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

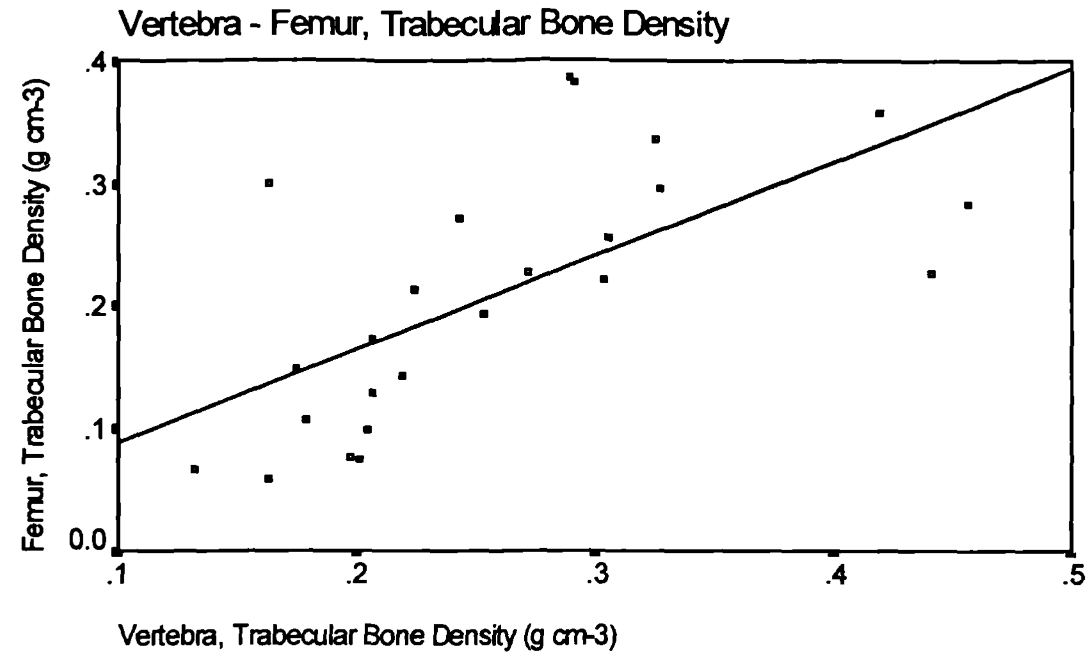


Figure 8.2.12 Vertebral body trabecular bone density plotted against femoral neck trabecular bone density. Correlation coefficient (Pearson) $r = 0.65$, $p < 0.001$. K-S (Lilliefors) p 0.0023.

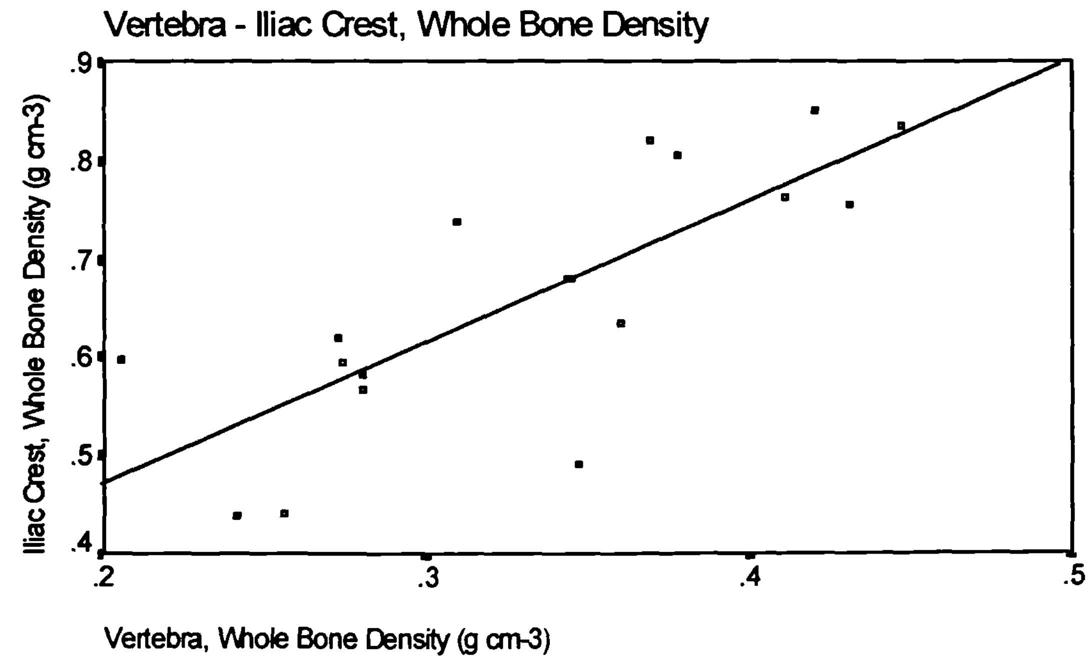


Figure 8.2.13 Vertebral body whole bone density plotted against Iliac crest whole bone density. Correlation coefficient (Pearson) $r = 0.72$, $p < 0.001$. K-S (Lilliefors) $p > 0.2000$.

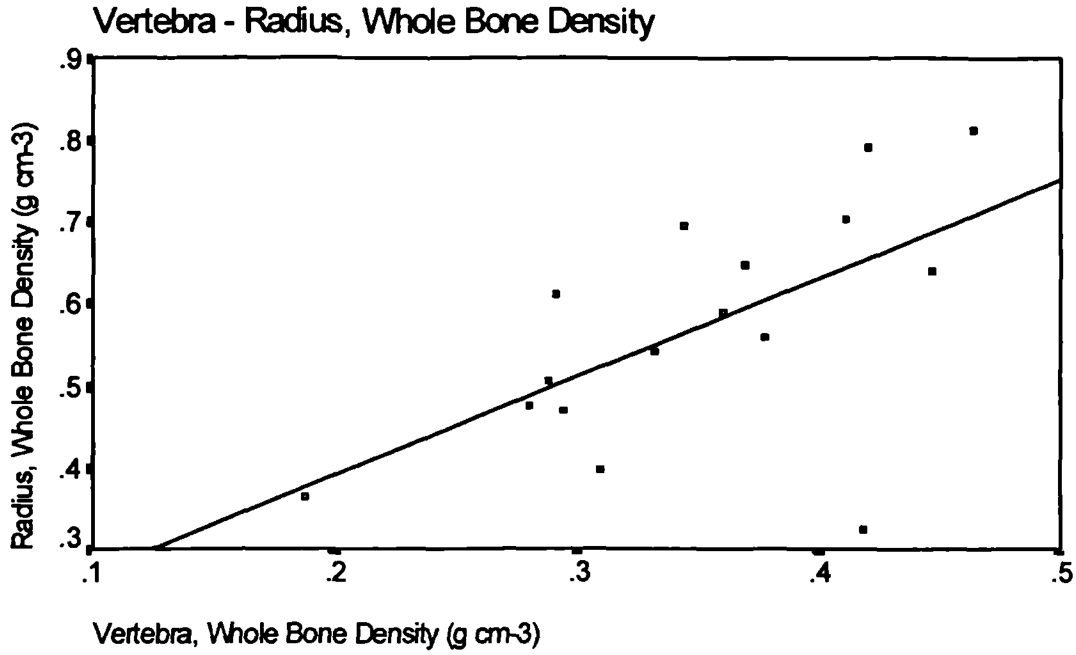


Figure 8.2.14 Vertebral body whole bone density plotted against whole bone density of the Radius. Correlation coefficient (Pearson) $r = 0.61$, $p = 0.011$. K-S (Lilliefors) $p = 0.1215$.

There was a moderate to strong positive correlation between density of the vertebral body and all other skeletal elements, from $r = 0.61$ for the radius to $r = 0.72$ for the iliac crest. In each case this was found to be significant. Although the correlations were not very strong, all were highly significant except the radius which was significant.

8.3 Optical Densitometry

Optical densitometry analysis of the whole bones and bone slices obtained from Redcross Way was performed using the methodology described in Section 7.3.3. In the current section, data has been compared to the base-line density data (Section 7.3.1) to assess the effectiveness of optical densitometry for determining bone mineral density. Analyses were performed on the same region of each individual bone as all other methods of analyses, including trabecular structure and cortical bone investigations. Raw data obtained from optical densitometry analysis is given in Tables 17-24 of Appendix III. Illustrations of bone slices, with results obtained from optical densitometry analysis are given in Section 7.8.

8.3.1 Whole Bone Optical Densitometry

8.3.1.1 Relationship between Whole Bone Optical Densitometry and Whole Bone Base-line Density

Figure 8.3.1 to Figure 8.3.3 show base-line whole bone density data of the femur, vertebral body, radius and iliac crest plotted against whole bone optical densitometry data.

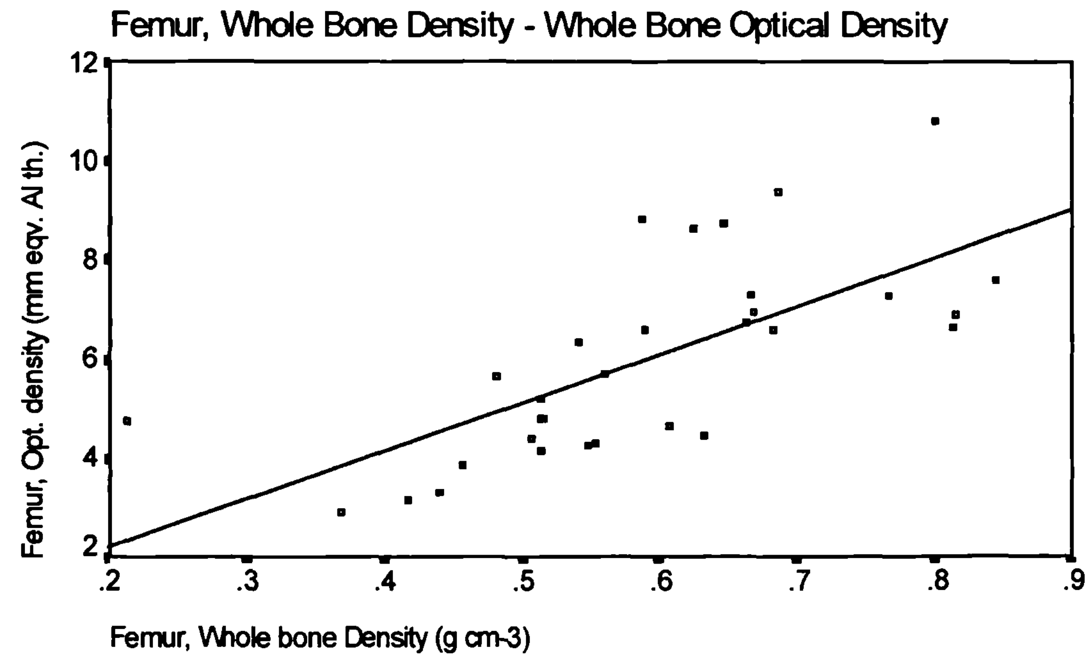


Figure 8.3.1 Femoral whole bone base-line density data plotted against whole bone optical densitometry data, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.70$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

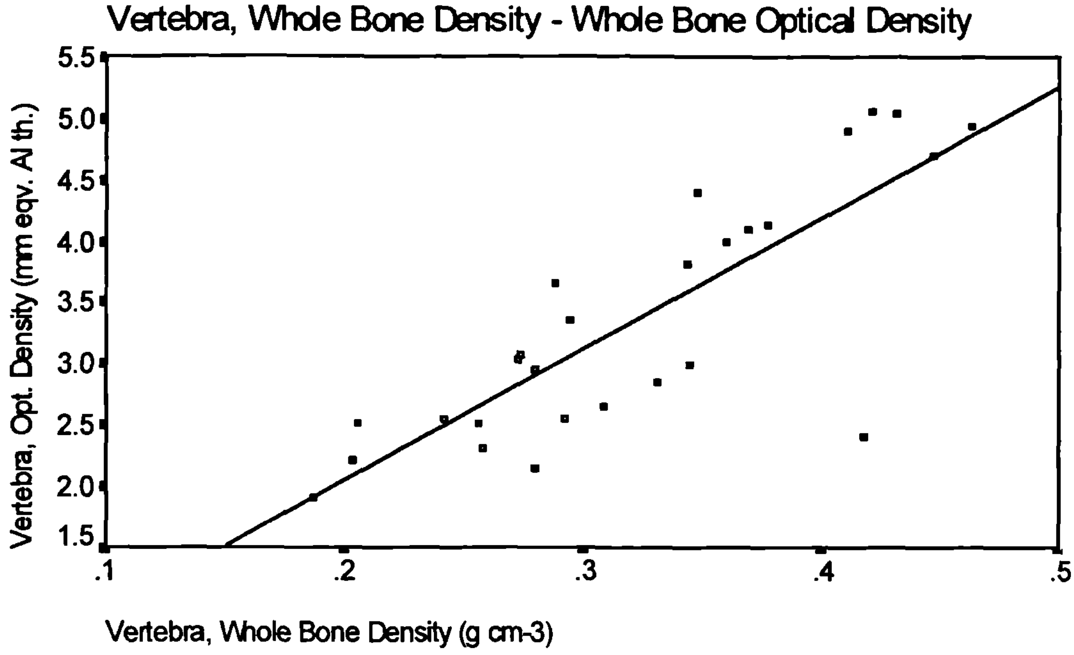


Figure 8.3.2 Vertebral body whole bone base-line density data plotted against whole bone optical densitometry, with least square regression line plotted. Rank correlation coefficient (Spearman) 0.82, significance < 0.0001.

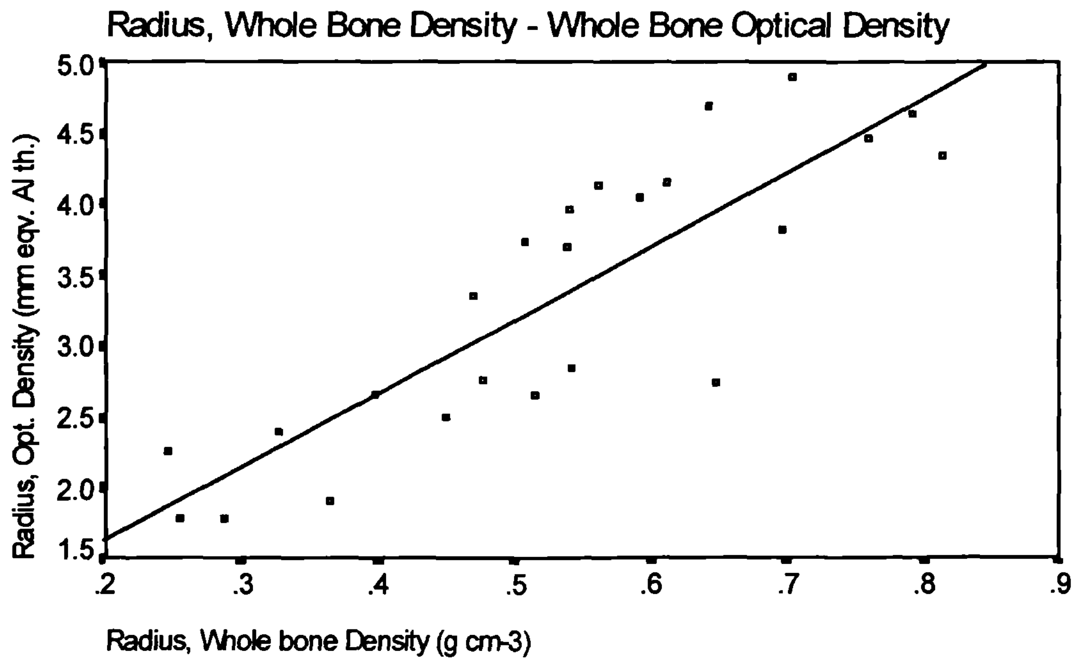


Figure 8.3.3 Radii whole bone base-line density data plotted against whole bone optical densitometry data, with least square regression line plotted. Rank correlation coefficient (Spearman) 0.88, significance < 0.0001.

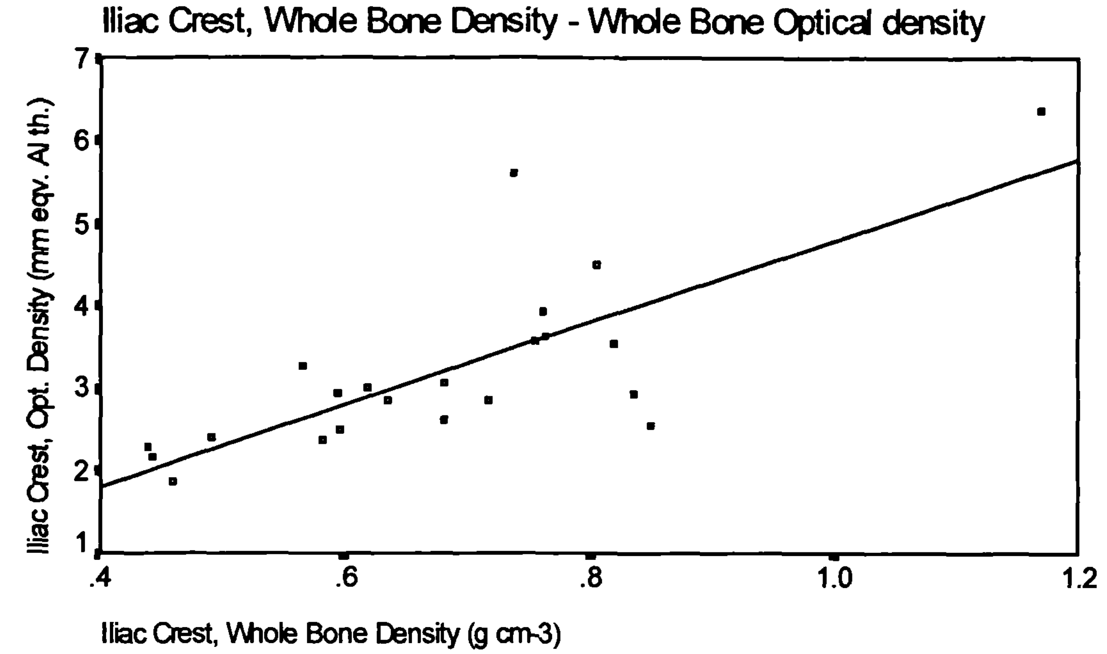


Figure 8.3.4 Ilia whole bone base-line density data plotted against whole bone optical densitometry data, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.77$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

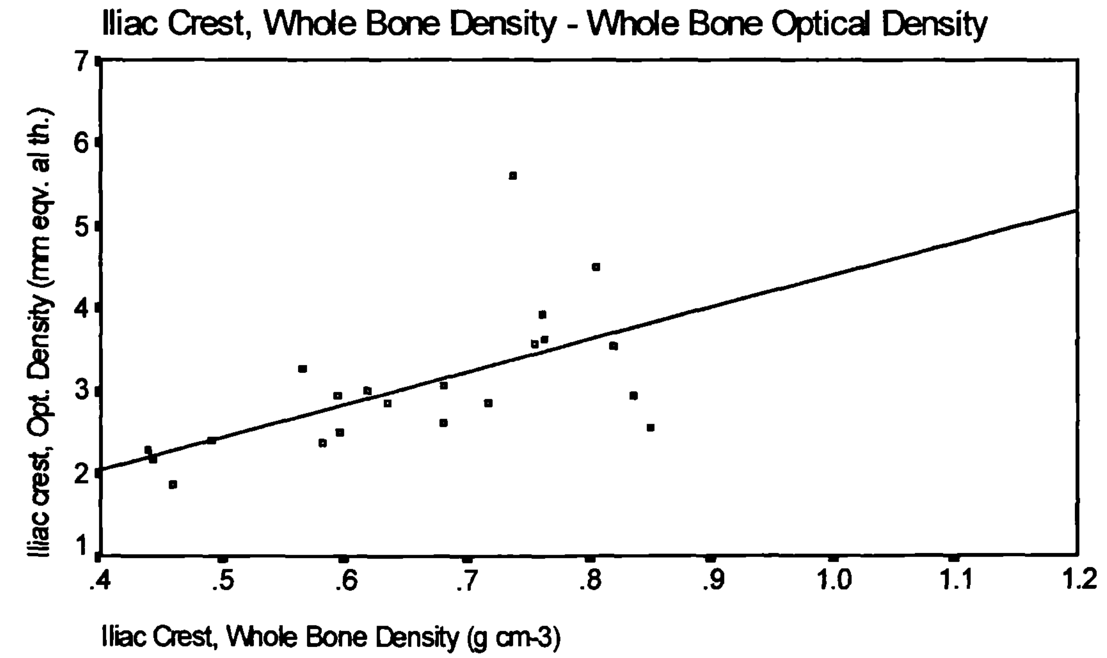


Figure 8.3.5 Ilia whole bone base-line density data plotted against whole bone optical densitometry data, with outlier removed. The least square regression line is plotted. Correlation coefficient $r = 0.60$, p 0.004. K-S (Lilliefors) 0.0004. Spearman rank correlation coefficient $r = 0.67$, significance 0.001.

A strong correlation was found between optical densitometry results and the base-line whole bone density data for all skeletal elements examined. The correlation produced was moderately strong in the femora and ilia, though the correlation was seen to fall for the ilia when the outlier (from a male estimated age 46+) was removed (Figure 8.3.5). In all cases the results were highly significant.

8.3.1.2 Relationship between Whole Bone Optical Densitometry and Trabecular Bone Base-line Density

Figure 8.3.6 to Figure 8.3.8 show trabecular bone base-line density the femur and the vertebral body plotted against whole bone optical densitometry data.

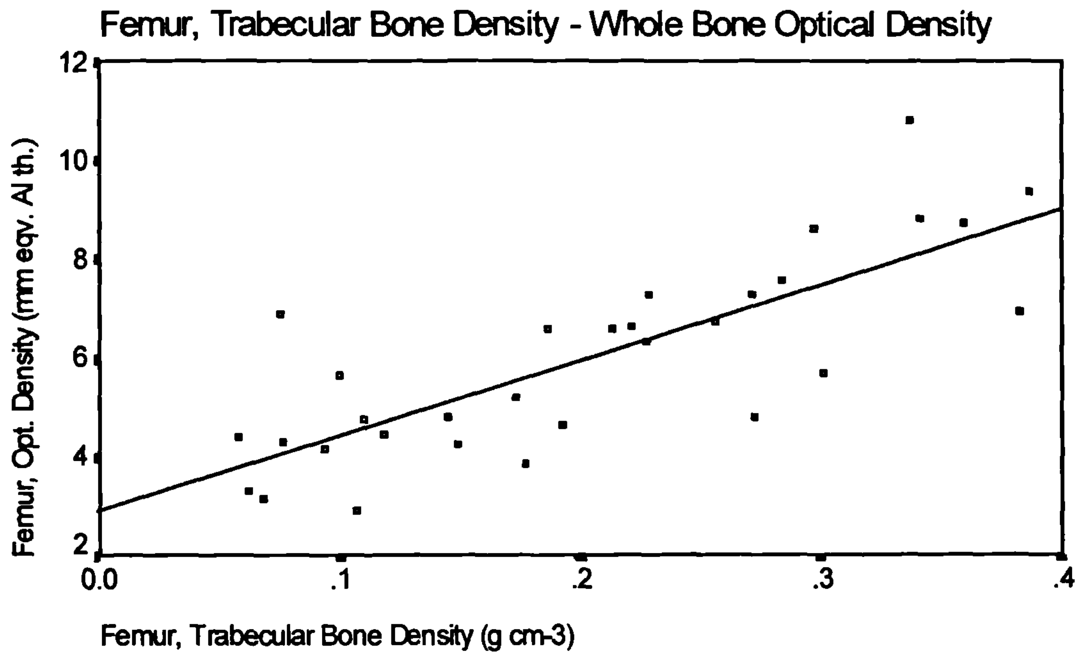


Figure 8.3.6 Femoral neck trabecular bone base-line density data plotted against whole bone optical densitometry data, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.79$, $p < 0.0001$. K-S (Lilliefors) p >0.2000.

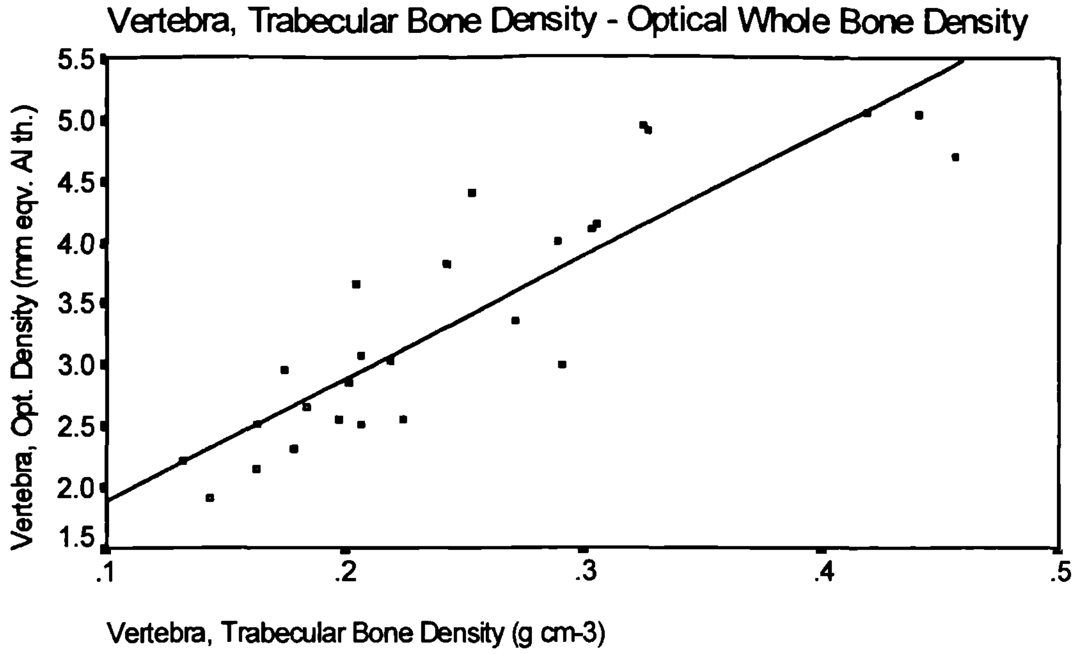


Figure 8.3.7 Vertebral body trabecular bone base-line density data plotted against whole bone optical densitometry data, with least square regression line plotted. Correlation coefficient (Pearson) r 0.88 p = < 0.0001. K-S (Lilliefors) p >0.2000.

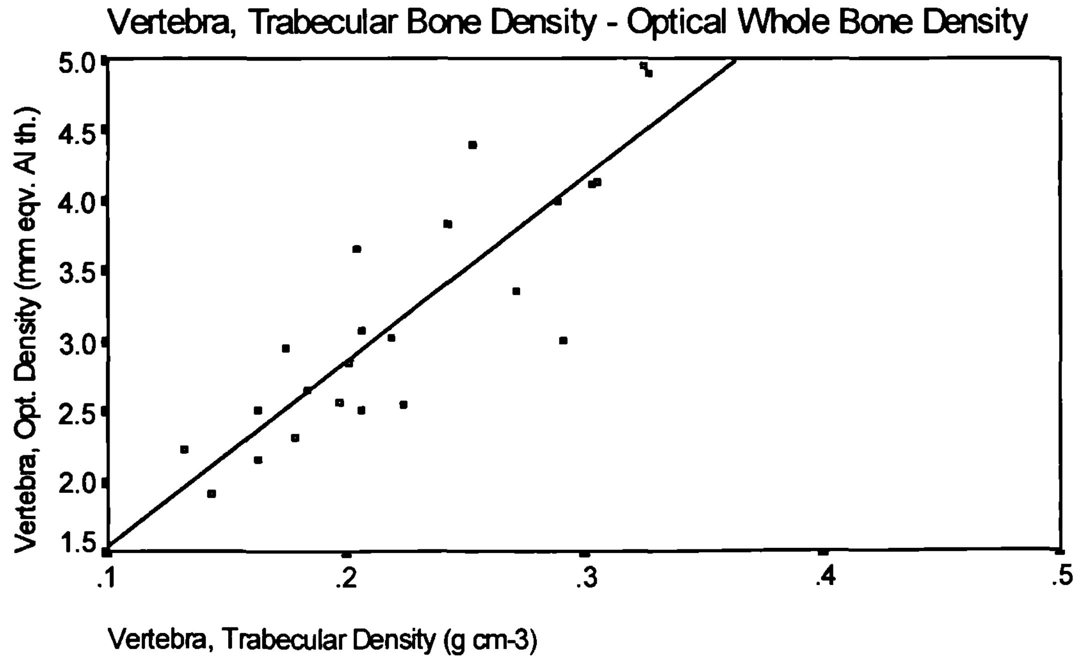


Figure 8.3.8 Vertebral body trabecular bone base-line density data plotted against whole bone optical densitometry data, with outliers removed. The least square regression line is plotted. Correlation coefficient (Pearson) r = 0.87 p < 0.0001. K-S (Lilliefors) p >0.2000.

A strong positive relationship occurred between the whole bone optical densitometry and the trabecular bone base-line density data for all samples. Removal of the outlier from the vertebral data (Figure 8.3.8) had little effect on the correlation produced. All the outliers originated from younger individuals.

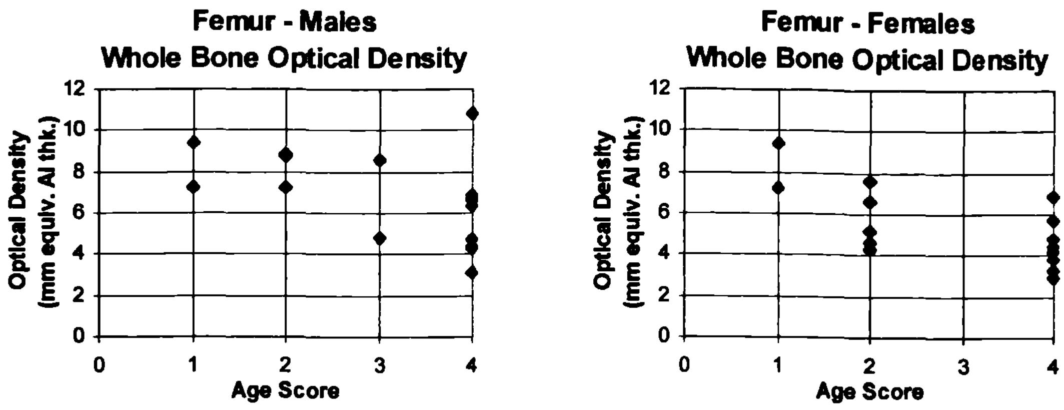
8.3.1.3 Relationship Between Age and Whole Bone Optical Densitometry

The relationship between the estimated age at death of individuals from which the sample material was obtained and the data obtained from whole bone optical densitometry is examined in this subsection. The skeletal elements examined were the femoral neck, the vertebral body, the radius and iliac crest. For all skeletal elements examined, sample numbers were not large enough for rigorous statistical analysis. Table 8.3.1 shows the number of individuals in each age/sex category for each skeletal element.

Figure 8.3.10 to Figure 8.3.12 show the estimated age at death plotted against bone slice optical densitometry for the femoral neck, vertebral body, radius and iliac crest.

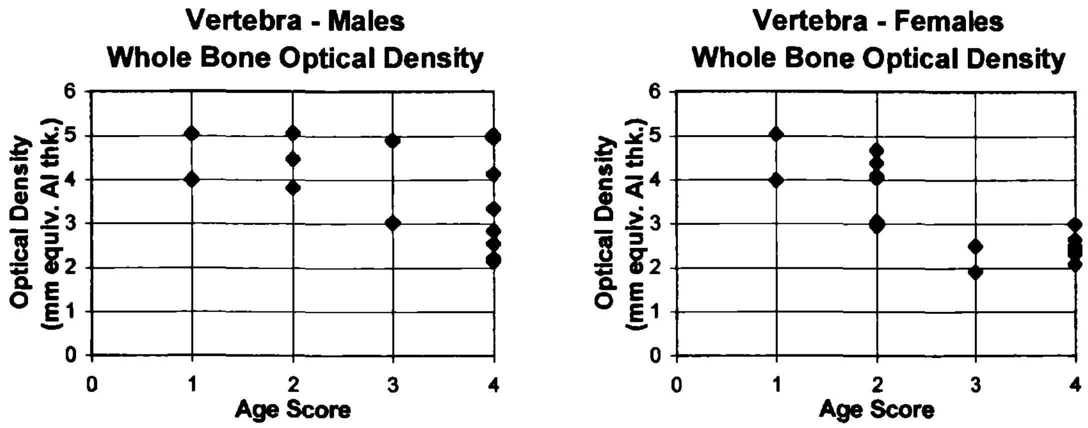
Age Category	Number			
	Femoral Neck	Vertebral Body	Radius	Iliac Crest
<25	2	2	2	2
m26-35	3	3	3	3
f26-35	6	6	3	5
m36-45	2	2	3	2
f36-45	0	2	2	1
m46+	9	9	8	5
f46+	8	6	8	4
Total	30	30	29	22

Table 8.3.1 The number of individuals in each age/sex category for the sample.



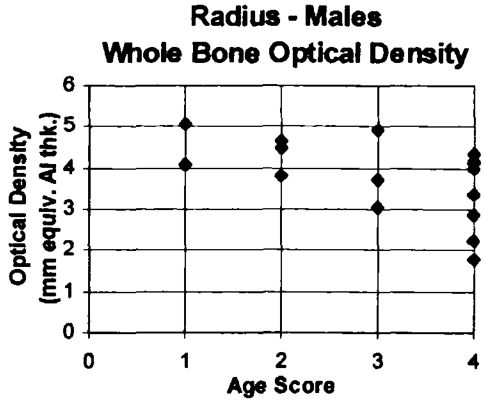
a) b)

Figure 8.3.9 Estimated age at death plotted against femoral neck whole bone optical densitometry results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+.

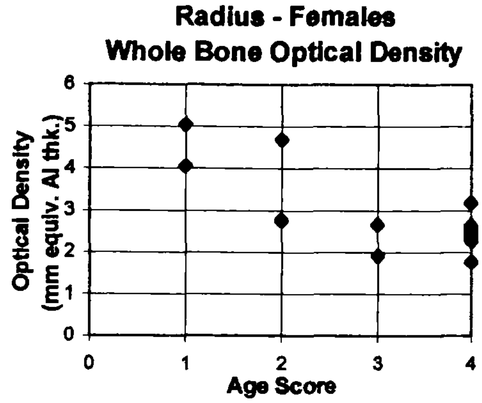


a) b)

Figure 8.3.10 Estimated age at death plotted against vertebral body whole bone optical densitometry results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+.

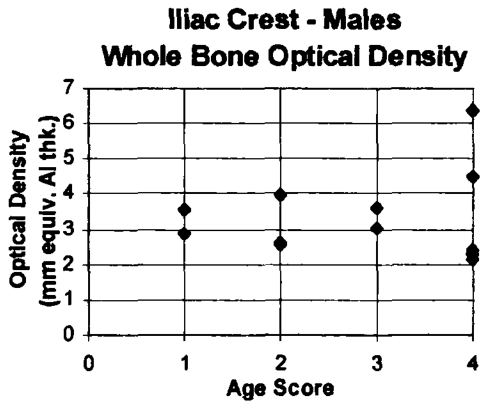


a)

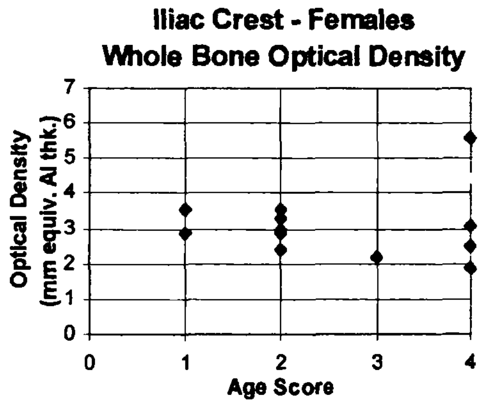


b)

Figure 8.3.11 Estimated age at death plotted against radius whole bone optical densitometry results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+.



a)



b)

Figure 8.3.12 Estimated age at death plotted against iliac crest whole bone optical densitometry results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+.

There appeared to be a decreasing optical density with age for all bones examined except for the iliac crest. The clearest trends are seen for the female femoral neck, female vertebral body and male radius. Similar trends were observed in the male femoral neck, male vertebral body and female radius. However, the trends in these three plots are less well defined because of the relatively limited numbers of data points in all of the three younger age categories.

8.3.2 Bone Slice Optical Densitometry

The data which had been obtained from the study of the whole bones using optical densitometry (full data in Tables 21-24 of Appendix III) was then compared to the base-line density data obtained.

8.3.2.1 Relationship between Bone Slice Optical Densitometry and Whole Bone Base-line Density

Figure 8.3.13 to Figure 8.3.17 show base-line whole bone density data of the femoral neck, vertebral body, radius and iliac crest plotted against whole bone optical densitometry data for the same skeletal elements.

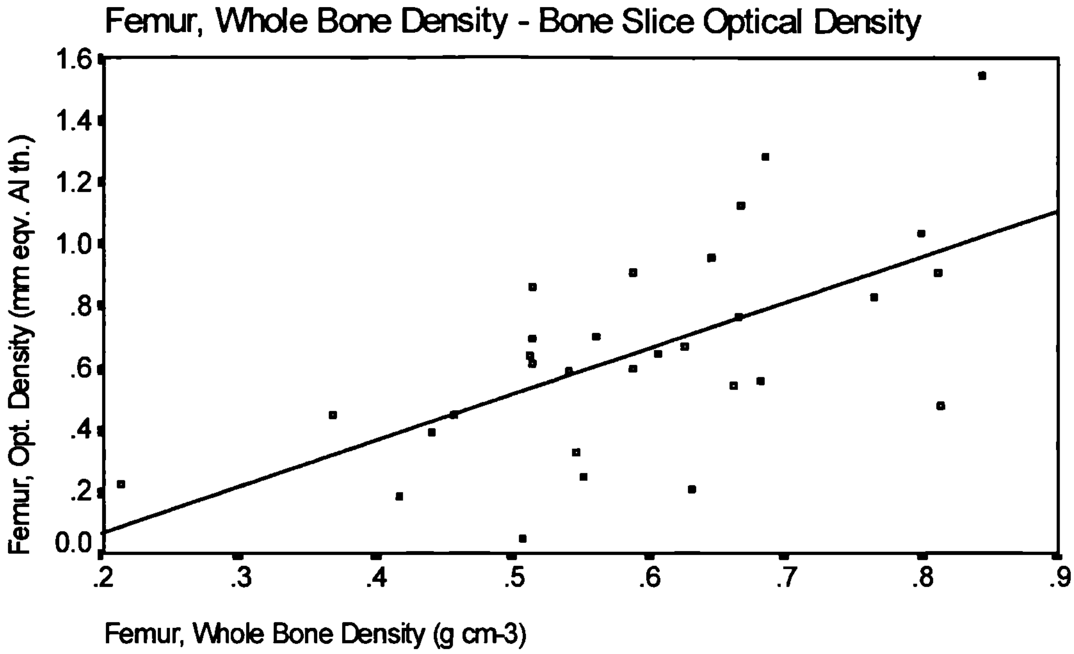


Figure 8.3.13 Femoral whole bone base-line density plotted against optical densitometry data obtained from femoral neck bone slices, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.62$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

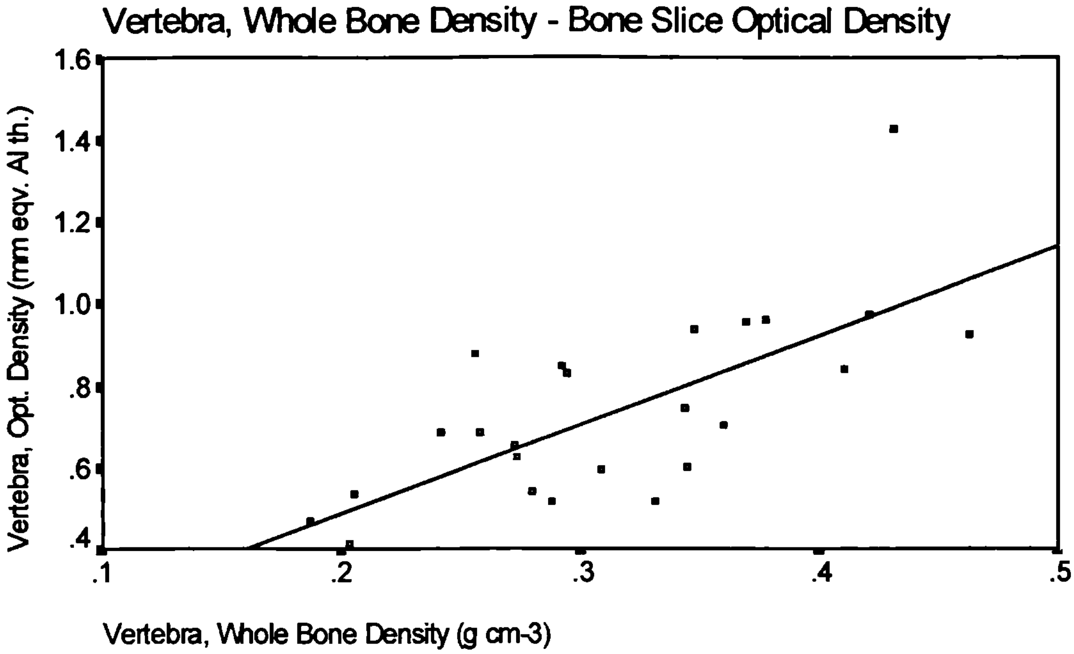


Figure 8.3.14 Vertebral body whole bone base-line density plotted against optical densitometry data obtained from the vertebral body bone slices. Correlation coefficient (Pearson) $r = 0.71$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

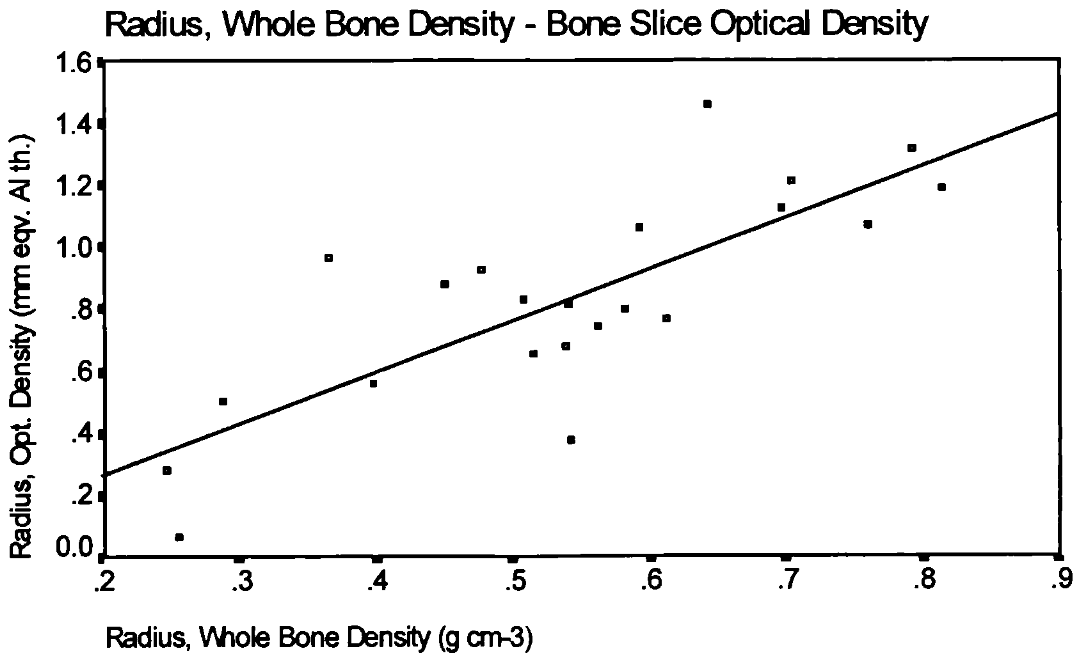


Figure 8.3.15 Radius whole bone base-line density plotted against optical densitometry data obtained from radius bone slices, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.80$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

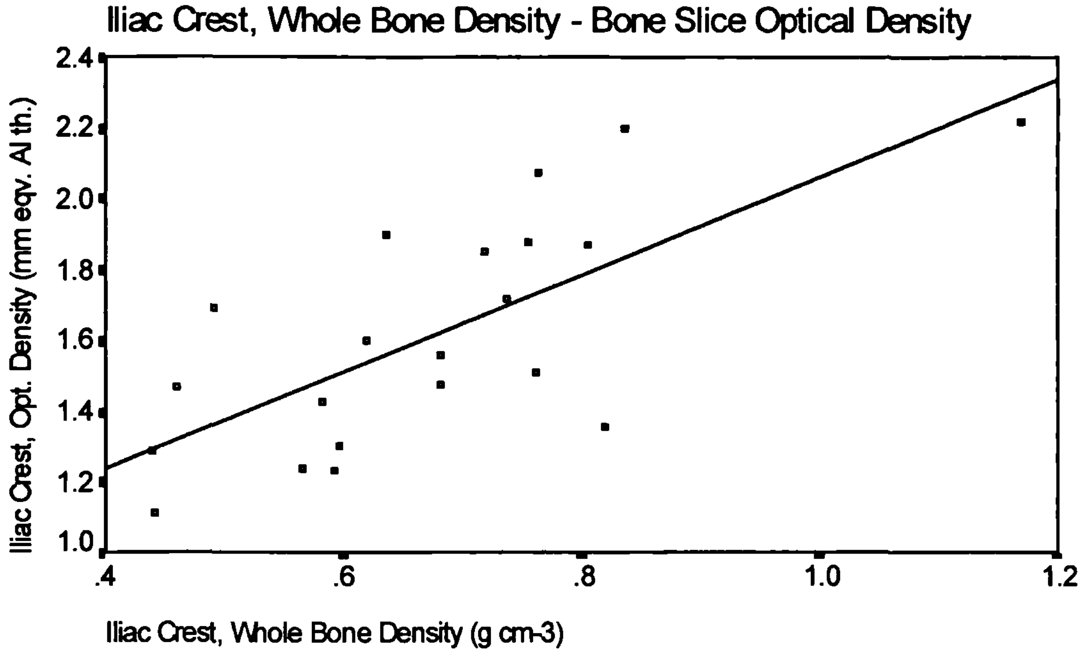


Figure 8.3.16 Iliac crest whole bone base-line density plotted against optical densitometry data obtained from Iliac crest bone slices, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.71$, $p < 0.0001$. K-S (Lilliefors) $p = 0.0501$.

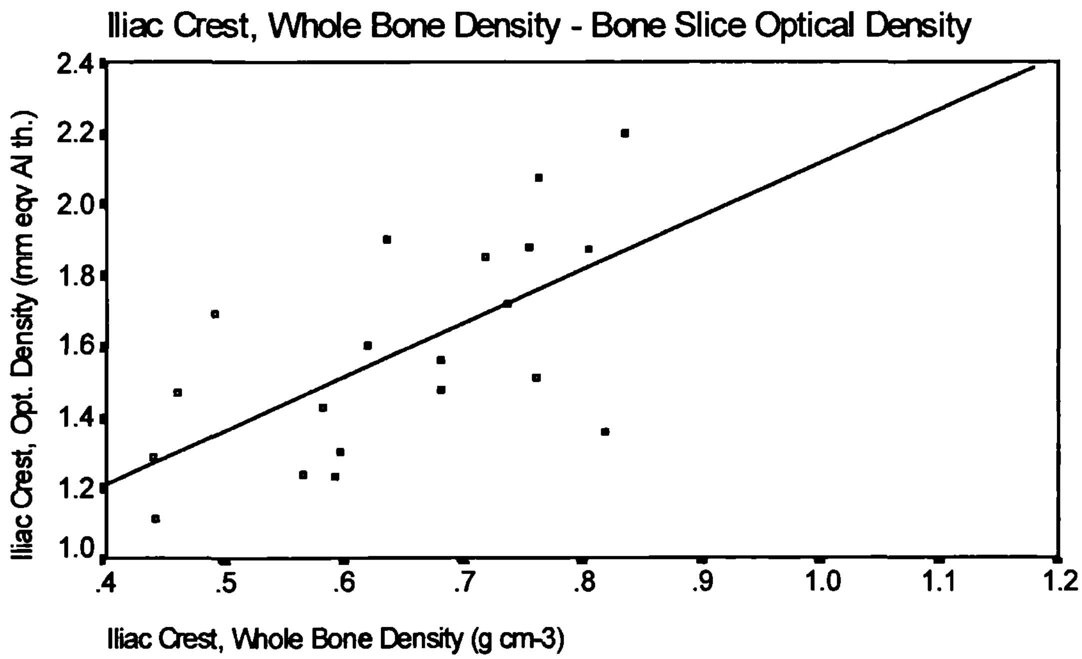


Figure 8.3.17 Iliac crest whole bone base-line density plotted against optical densitometry data obtained from iliac crest bone slices, with the outlier removed. The least square regression line is plotted. Correlation coefficient (Pearson) $r = 0.63$, $p = 0.003$. K-S (Lilliefors) >0.2000.

A moderate positive correlation between optical densitometry measurements from the radiographs and whole bone density was found for the femoral neck and iliac crest. A strong positive correlation was found between optical densitometry data base-line density data for the vertebral bodies and radii. In all cases the correlations obtained were seen to be significant. The correlation calculated for the iliac crest with outliers removed was slightly lower than the correlation including the outlier. The iliac crest which produced the anomalous result originated from a male with an estimated age of 46+. It was considered an outlier because the base-line density was high for the age category. It is therefore interesting to note that the outlier plots very close to the regression line (Figure 8.3.16), suggesting that this outlier has not been caused by measurement error.

8.3.2.2 Relationship between Bone Slice Optical Densitometry and Base-line Trabecular Bone Density

Figure 8.3.18 and Figure 8.3.19 show trabecular bone base-line density of the femoral neck and vertebral body plotted against whole bone optical densitometry data for the same skeletal elements.

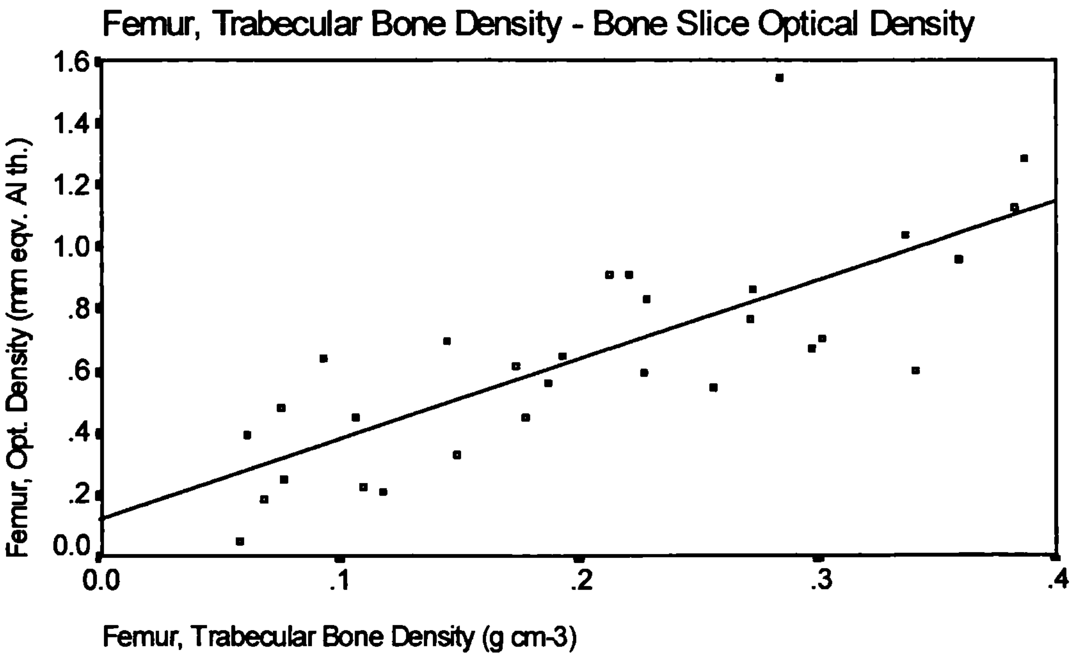


Figure 8.3.18 Femoral neck trabecular bone base-line density plotted against optical densitometry data obtained from the femoral bone slices, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.78$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

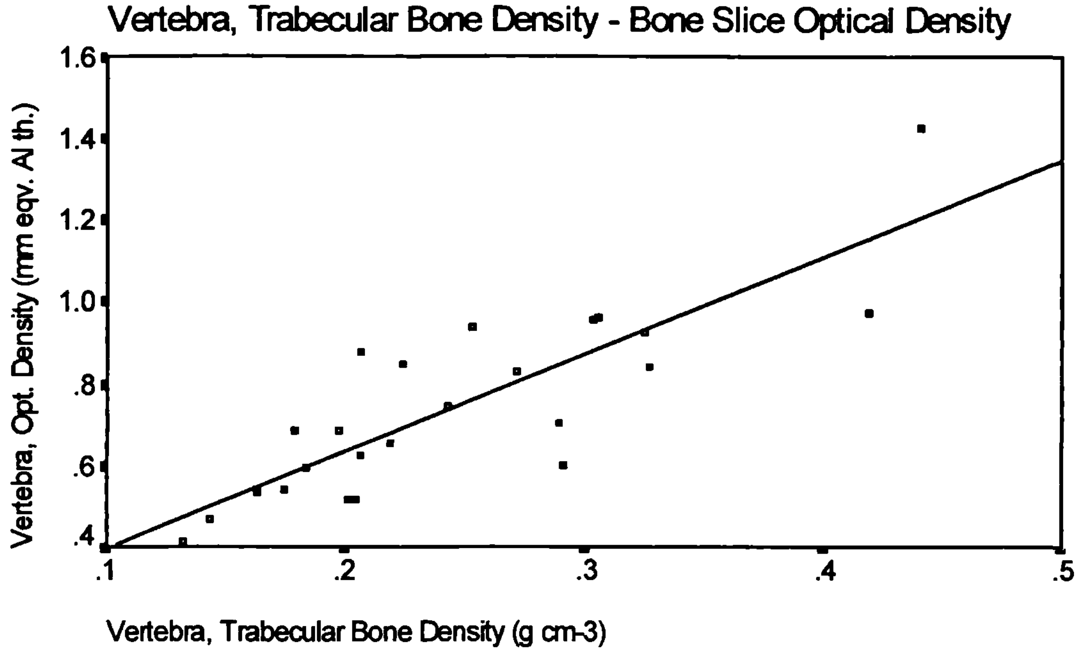


Figure 8.3.19 Vertebral body trabecular bone base-line density plotted against optical densitometry data obtained from the vertebral body bone slices, with least square regression line plotted. Correlation coefficient (Spearman) $r = 0.84$, significance < 0.0001.

A comparison of the base-line trabecular bone density and the bone slice optical densitometry data showed a moderate positive correlation in the case of the femur, and a strong positive correlation for the vertebral bodies. In both the femoral necks and the vertebral bodies the correlation was significant.

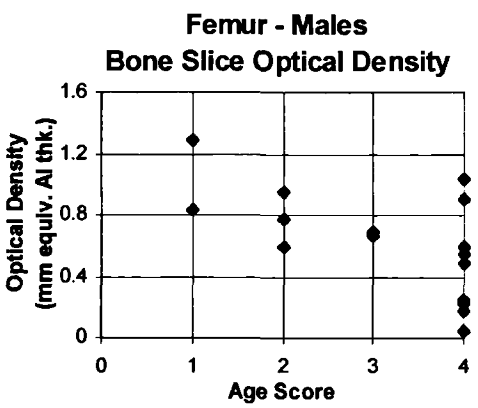
8.3.2.3 Relationship between Age/Sex and Bone Slice Optical Densitometry

The relationship between the estimated age at death of individuals from which the sample material was obtained and the data obtained from optical densitometry analysis of the bone slices are examined in this subsection. The skeletal elements examined are the femoral neck, vertebral body, radius and iliac crest. For all selected elements examined, sample numbers were not large enough for rigorous statistical analysis. Table 8.3.2 shows the number of individuals in each age/sex category for each skeletal element.

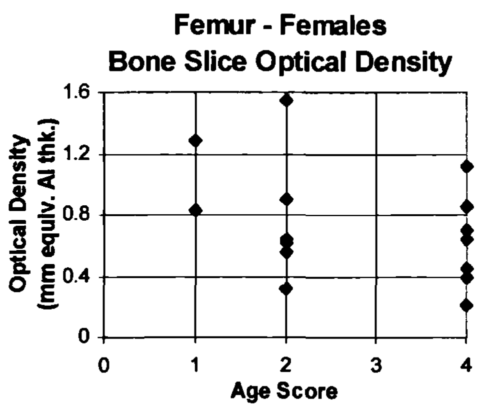
Age Category	Number			
	Femoral Neck	Vertebral Body	Radius	Iliac Crest
>25	2	2	1	2
m26-35	3	2	3	2
f26-35	6	4	3	6
m36-45	2	2	1	2
f36-45	0	2	1	1
m46+	9	8	7	6
f46+	8	4	5	3
Total	30	24	21	22

Table 8.3.2 The number of femoral neck, vertebral body, radius and iliac crest samples in each age/sex category for which bone slice optical densitometry data was obtained.

Figure 8.3.20 to Figure 8.3.23 show the estimated age at death plotted against optical densitometry data for the bone slices for the femoral neck, vertebral body, radius and iliac crest.

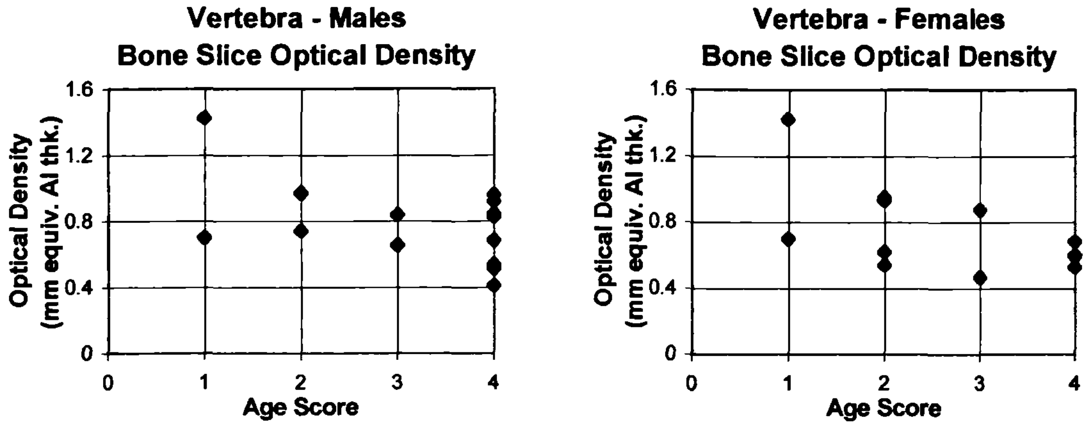


a)



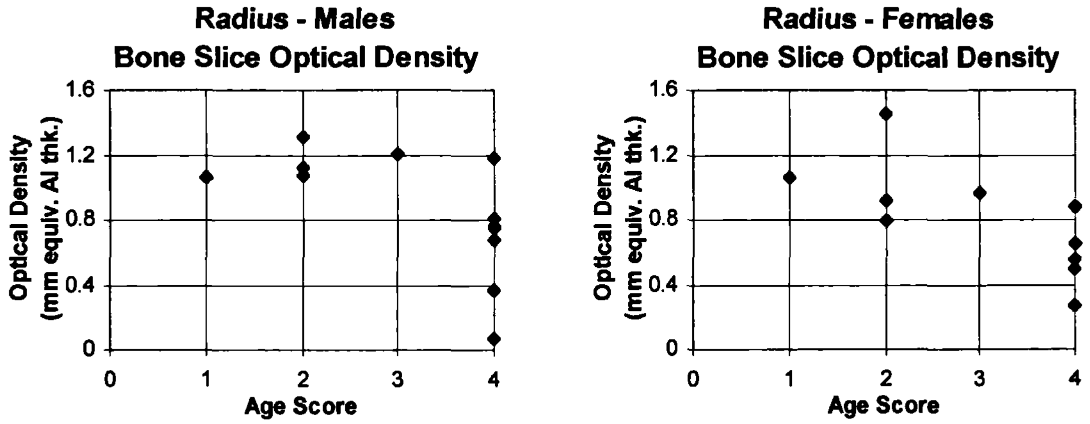
b)

Figure 8.3.20 Estimated age at death plotted against femoral neck whole bone density results for a) males and b) females. Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.



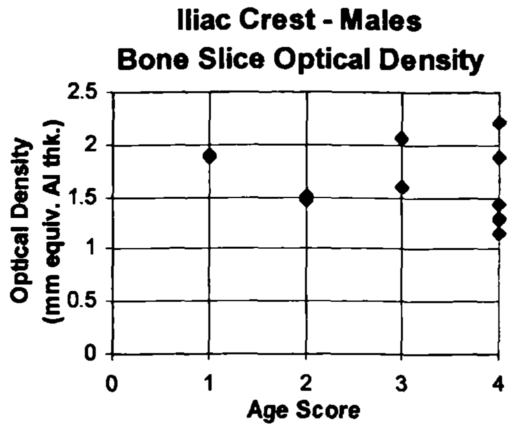
a) b)

Figure 8.3.21 Estimated age at death plotted against vertebral bodies bone slice optical densitometry results for a) males and b) females. Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.

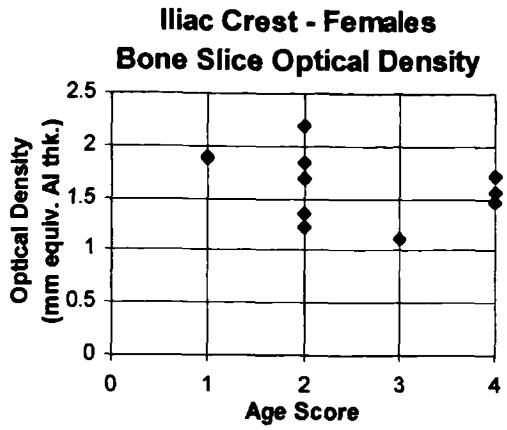


a) b)

Figure 8.3.22 Estimated age at death plotted against radius bone slice optical densitometry results for a) males and b) females. Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.



a)



b)

Figure 8.3.23 Estimated age at death plotted against iliac crests bone slice optical densitometry results for a) males and b) females. Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.

There appeared to be a decrease in optical densitometry with age for all bones examined for males and females, except for the iliac crest. However, it should be noted that in many cases the trends were marked by only one or two data points, particularly in the youngest three age categories.

It should be noted that the pattern in these plots could be different if sample numbers were greater.

8.4 Dual Energy X-ray Absorptiometry (DEXA)

DEXA analysis of the whole bone was performed using the methodology described in Section 7.3.4. In the current section, data has been compared to the base-line density data (Section 7.3.1) to assess the effectiveness of DEXA for determining bone mineral density. Raw data obtained from DEXA analysis is given in Tables 11-14 of Appendix III. Section 7.8 contains illustrations of sample slices with results of DEXA analyses given in tables below. Analyses were performed on the same region of interest of each individual bone as all other methods of analysis, including trabecular structure and cortical bone investigations.

8.4.1 Relationship between DEXA Data and Whole Bone Base-line Density

Figure 8.4.1 to Figure 8.4.5 show base-line whole bone density data of the femoral neck, vertebral body, radius and iliac crest plotted against DEXA data for the same skeletal elements.

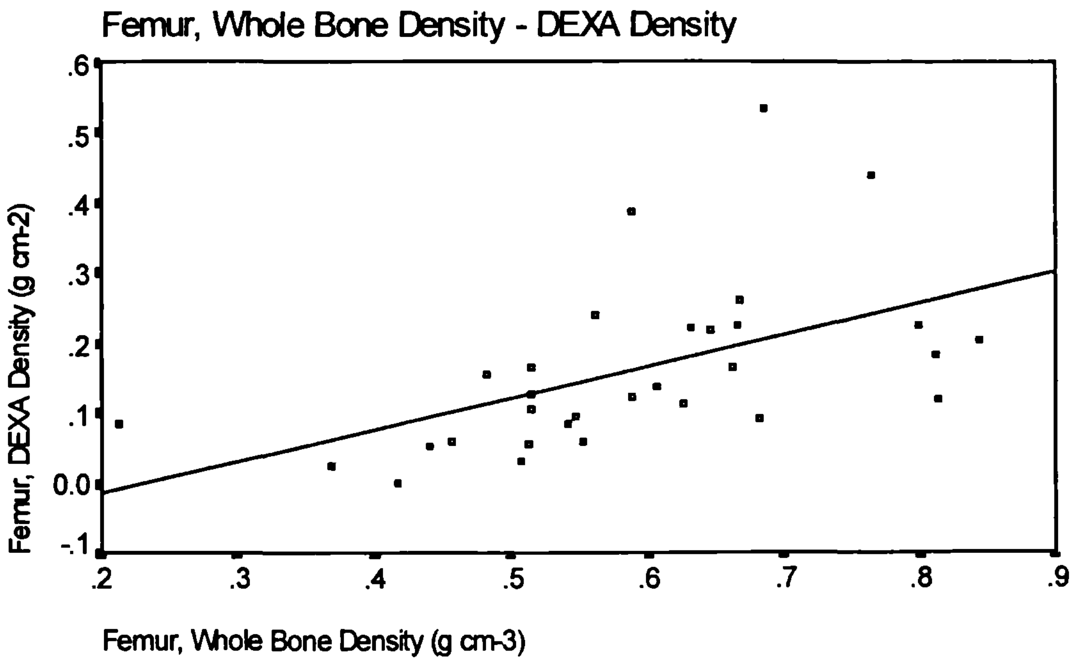


Figure 8.4.1 Femoral whole bone base-line density data plotted against DEXA data, with the least square regression line plotted. Correlation coefficient (Pearson) $r = 0.52$, $p < 0.0001$. K-S (Lilliefors) $p = 0.0670$.

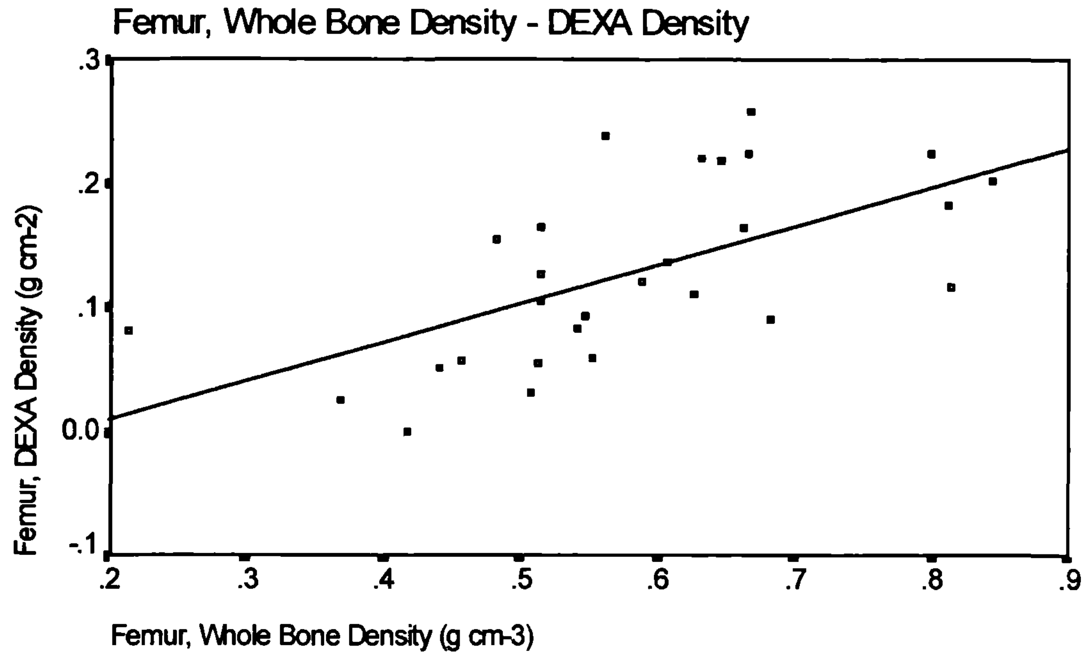


Figure 8.4.2 Femora whole bone base-line density data plotted against DEXA data from the femoral neck with outliers removed. The least square regression line is plotted. Correlation coefficient (Pearson) r = 0.61, p < 0.0001. K-S (Lilliefors) p > 0.2000.

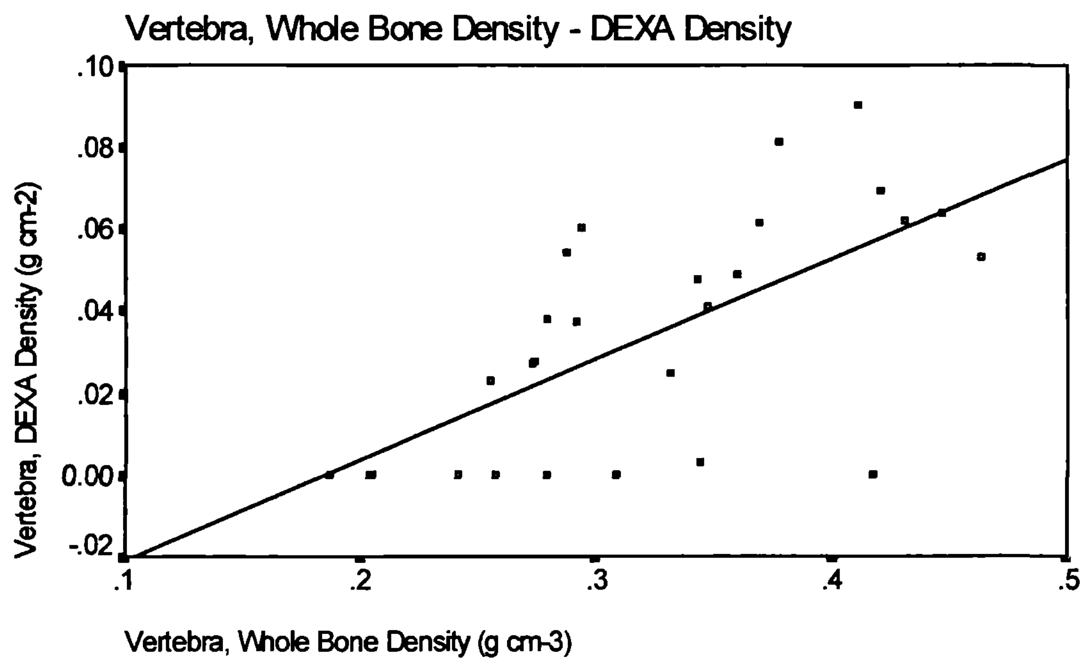


Figure 8.4.3 Vertebral body whole bone base-line density data plotted against DEXA data obtained from the vertebral body, with the least square regression line plotted. Correlation coefficient (Pearson) r = 0.65, p < 0.0001. K-S (Lilliefors) p >0.2000.

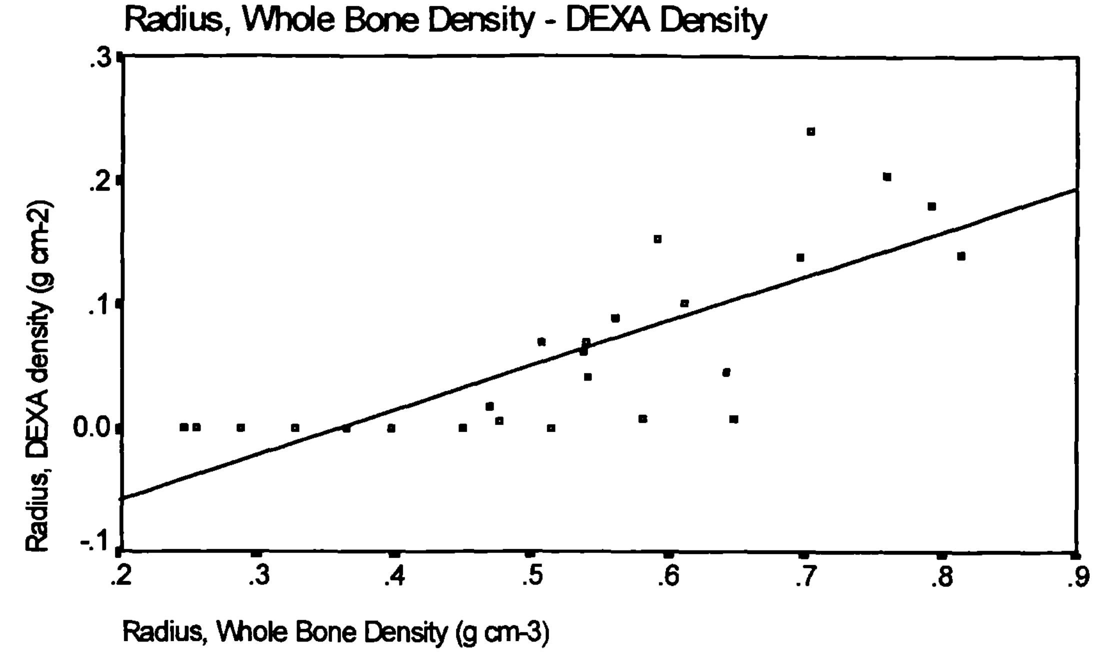


Figure 8.4.4 Radius whole bone base-line density data plotted against DEXA data obtained from the radius, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.77$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

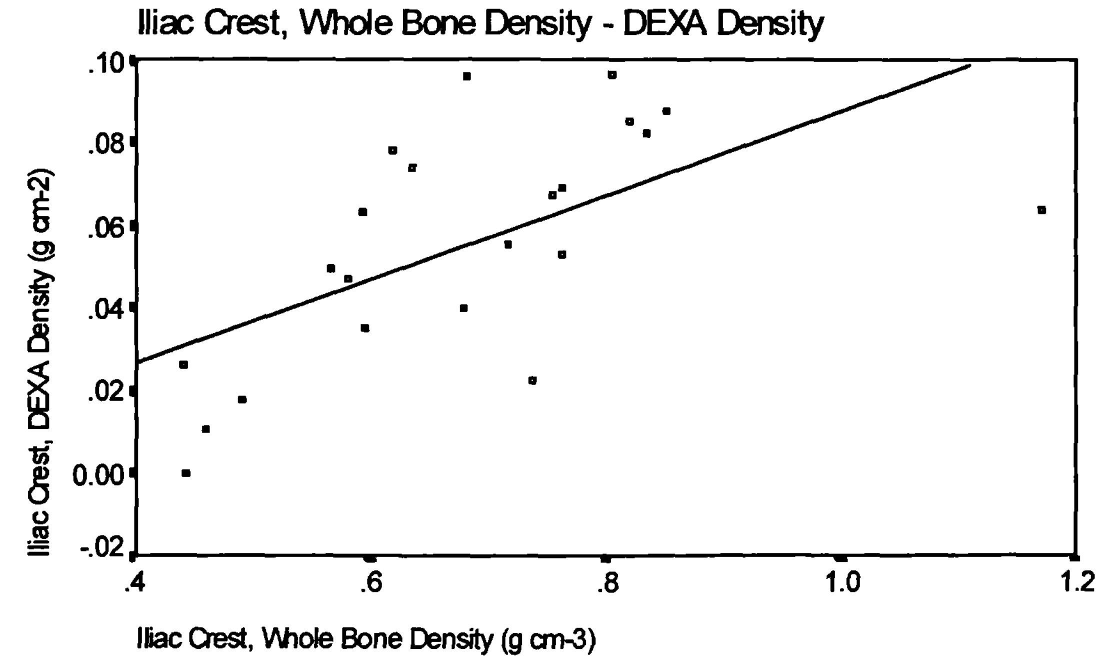


Figure 8.4.5 Iliac crest whole bone base-line density data plotted DEXA data obtained from the iliac crest, with the least square regression line plotted. Correlation coefficient (Pearson) $r = 0.70$, $p < 0.0001$. K-S (Lilliefors) $p = > 0.2000$.

A moderate positive correlation was found between DEXA measurements and whole bone density for the femoral neck and vertebral body. For the radius and iliac crest there was a strong positive correlation. All correlations obtained were found to be significant. It was found that the

DEXA equipment was unable to detect bones of very low density. For these bones of very low density the DEXA analysis returned a value of zero (Figures 7.8.3 and 7.8.12). The strongest correlation was observed for the radius. When outliers produced from analysis of the femoral neck were removed, the correlation coefficient increased to 0.61. Bone which produced anomalous results all originated from younger individuals; two in the age category <26 years, one in the age category 26-35 years.

8.4.2 Relationship between DEXA Data and Trabecular Bone Base-line Density

Figure 8.4.6 to Figure 8.4.8 show trabecular bone base-line density of the femoral neck and vertebral body plotted against DEXA data for the same skeletal elements.

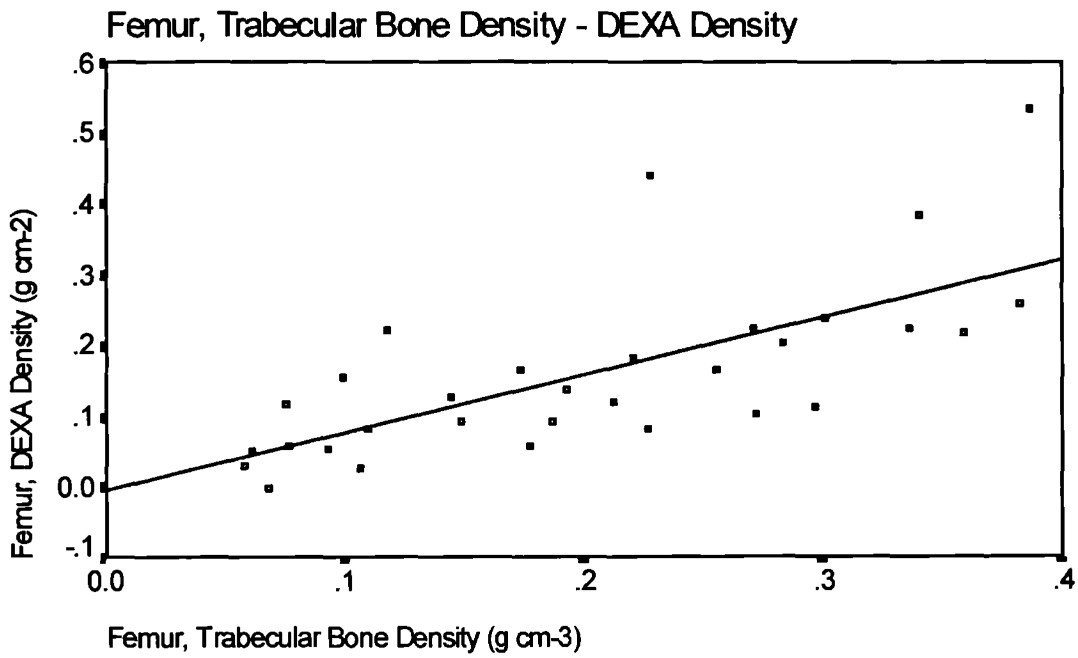


Figure 8.4.6 Femoral trabecular bone base-line density plotted against DEXA data, with line of least square regression plotted. Correlation coefficient (Pearson) $r = 0.69$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

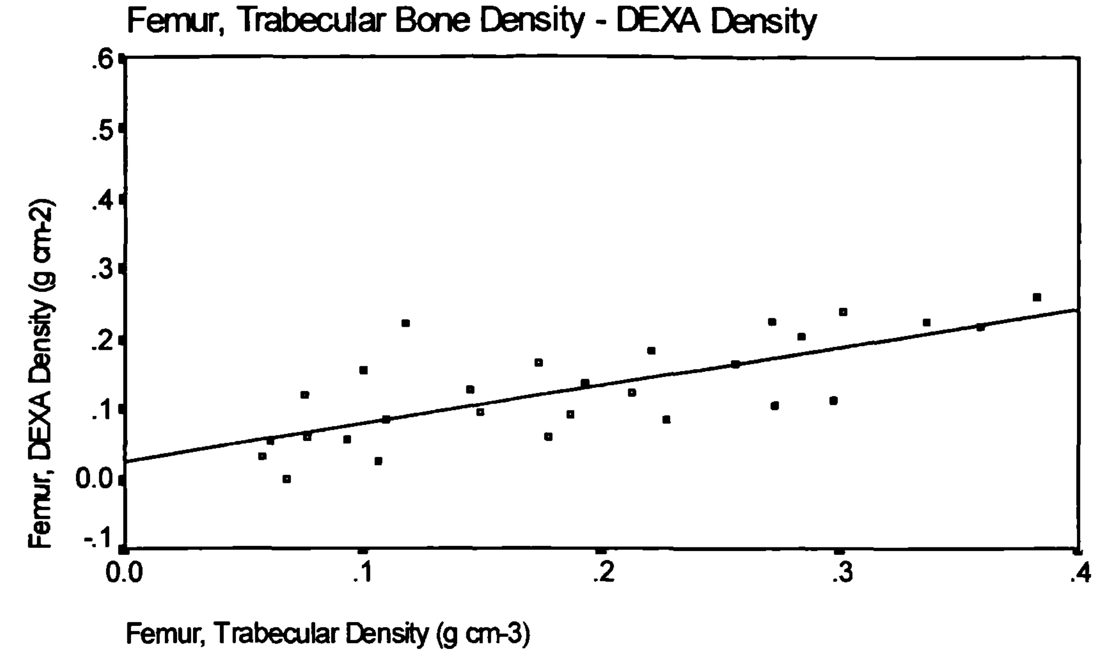


Figure 8.4.7 Femoral trabecular bone base-line density plotted against DEXA data with outliers removed. The line of least square regression is plotted. Correlation coefficient (Pearson) $r = 0.73$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

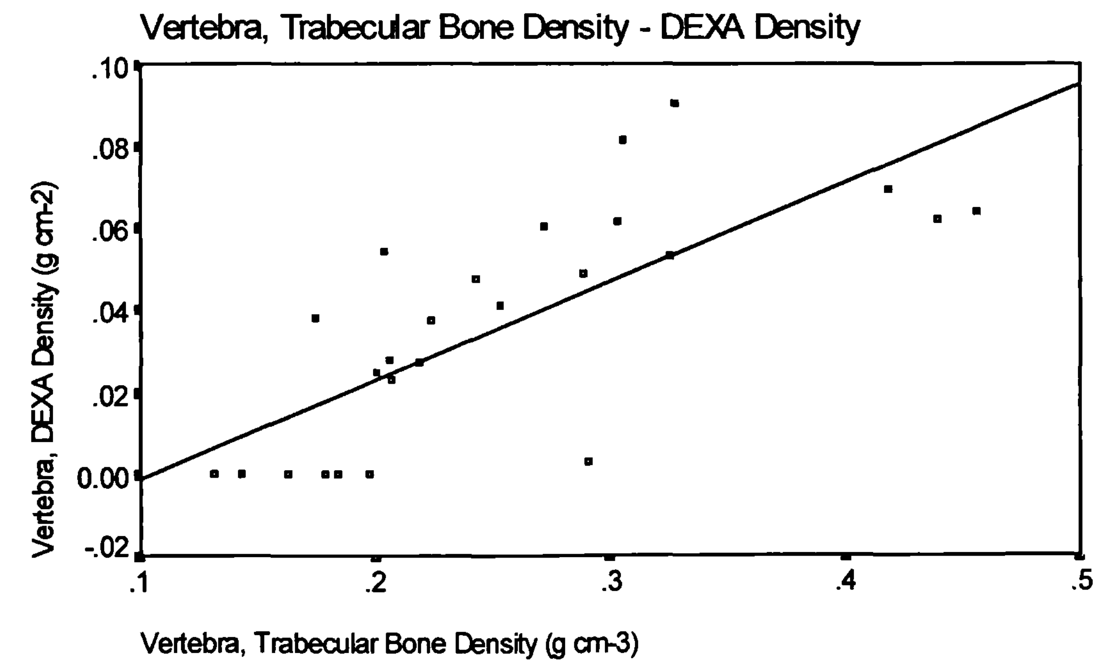


Figure 8.4.8 Vertebral body trabecular base-line bone density plotted against DEXA data, with line of least square regression plotted. Rank correlation coefficient (Spearman) $r = 0.80$, significance < 0.0001.

A fairly strong significant positive correlation between DEXA measurements and trabecular bone density was found for the vertebral body, iliac crest and radius. That for the femoral neck was found to be moderate. However, for each bone type studied there were a number of samples for which the DEXA analysis returned a value of zero, especially from the vertebral bodies. When the outliers were removed from the femoral neck data, the correlation coefficient increased to 0.73. As in the whole bone density data (Section 8.4.1), the outliers were produced by younger individuals, two in age category 25-25 years and one in the category 26-35 years.

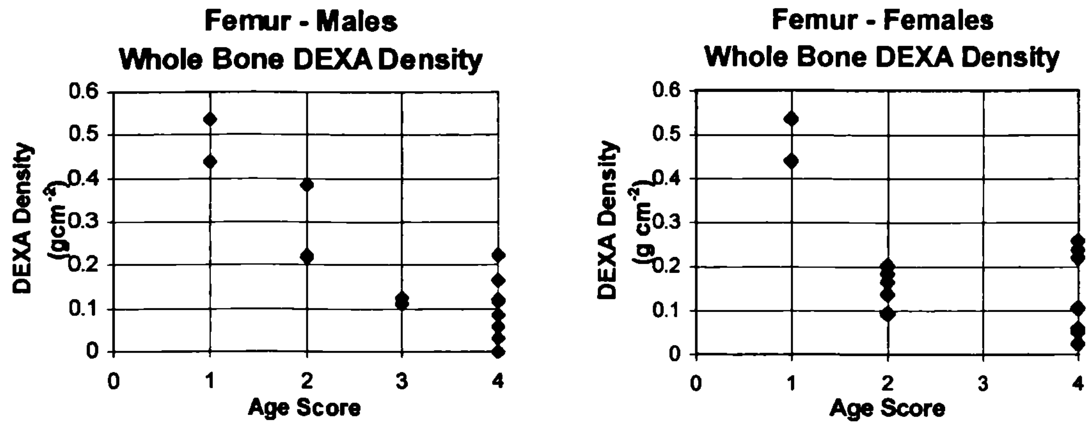
8.4.3 Relationship between Age/Sex and DEXA Density

The relationship between the estimated age at death of individuals from which the sample material was obtained and the DEXA data are examined in this section. The skeletal elements examined are, the femoral neck, the vertebral body, the radius and the iliac crest. For all skeletal elements examined sample numbers were not large enough for rigorous statistical analysis. Table 8.4.1 shows the numbers of individuals in each age/sex category for each skeletal element.

Figure 8.4.9 to Figure 8.4.12 show the estimated age at death plotted against DEXA data for the, femoral neck, vertebral body, radius and iliac crest.

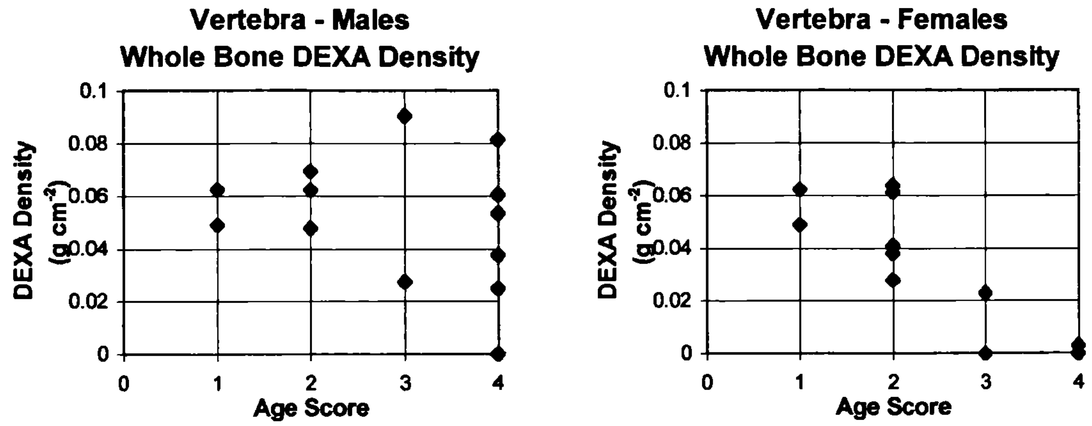
Age/Sex Category	Number			
	Femoral Neck	Vertebral Body	Radius	Iliac Crest
<25	2	2	1	2
m26-35	3	3	3	3
f26-35	6	5	4	6
m36-45	2	2	2	2
f36-45	0	2	2	2
m46+	9	8	8	5
f46+	8	6	9	3
Total	30	28	29	23

Table 8.4.1 Number of samples from each bone in each age/sex category for which DEXA data was obtained.



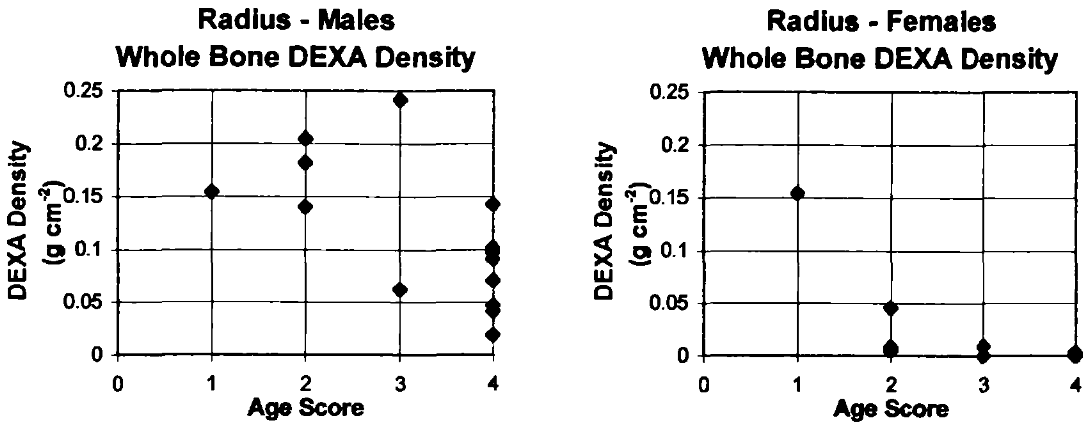
a) b)

Figure 8.4.9 Estimated age at death plotted against femoral neck DEXA results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.



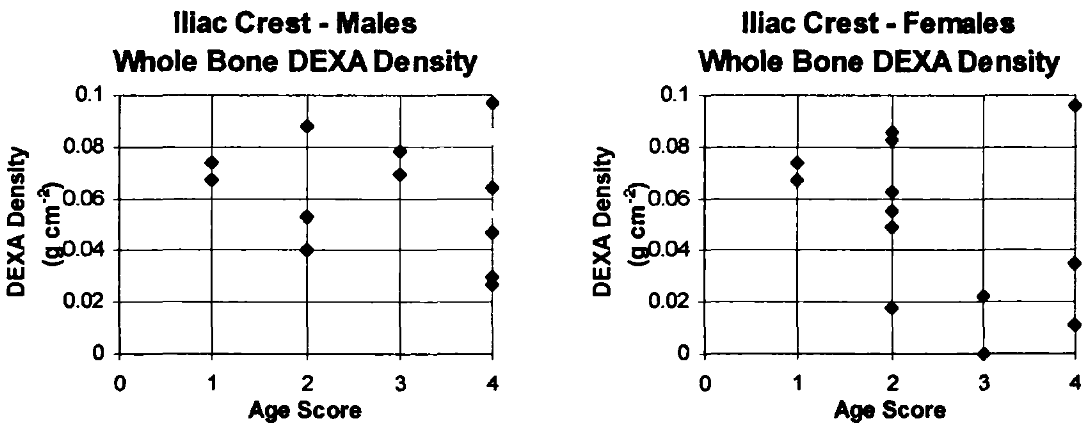
a) b)

Figure 8.4.10 Estimated age at death plotted against vertebral body DEXA results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.



a) b)

Figure 8.4.11 Estimated age at death plotted against radius DEXA data results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.



a) b)

Figure 8.4.12 Estimated age at death plotted against iliac crest DEXA results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.

Analysis of these plots is difficult because of measurements of 0 g cm^2 hydroxylapatite on bones of very low density. Possible trends in the female radius plot were not considered because most of the measurements were zero. There appeared to be a decreasing density (g cm-^{2} hydroxylapatite) for the male femoral neck, female vertebral body, and male radius. However, in all these three plots, the number of data points were relatively few in age categories 25-26 years and 36-45 years. The trend appeared less well defined for the category 36-45 years. It should be noted that, the female femur showed no apparent change between age categories 26-35 years and 46+ years, but these two age categories had a much lower density (g cm-^{2} hydroxylapatite) than the age category 15-26 years.

It should be noted that the pattern in these plots could be different if sample numbers were greater.

8.5 Low Angle X-ray Scattering (LAXS)

LAXS analysis of the whole bone density was performed using the methodology described in Section 7.3.5. In the current section, data have been compared with the base-line density data (Section 7.3.1) to assess the effectiveness of LAXS for determining bone mineral density. Raw data obtained from LAXS analysis is given in Tables 15 and 16 of Appendix III. Analyses were performed on the same region of interest as all other methods of analysis, including trabecular structure and cortical bone investigations.

8.5.1 Relationship between LAXS data and Whole Bone Base-line Density

Figure 8.5.1 and Figure 8.5.2 show base-line whole bone density data for the femoral neck and vertebral body plotted against LAXS data for the same skeletal elements.

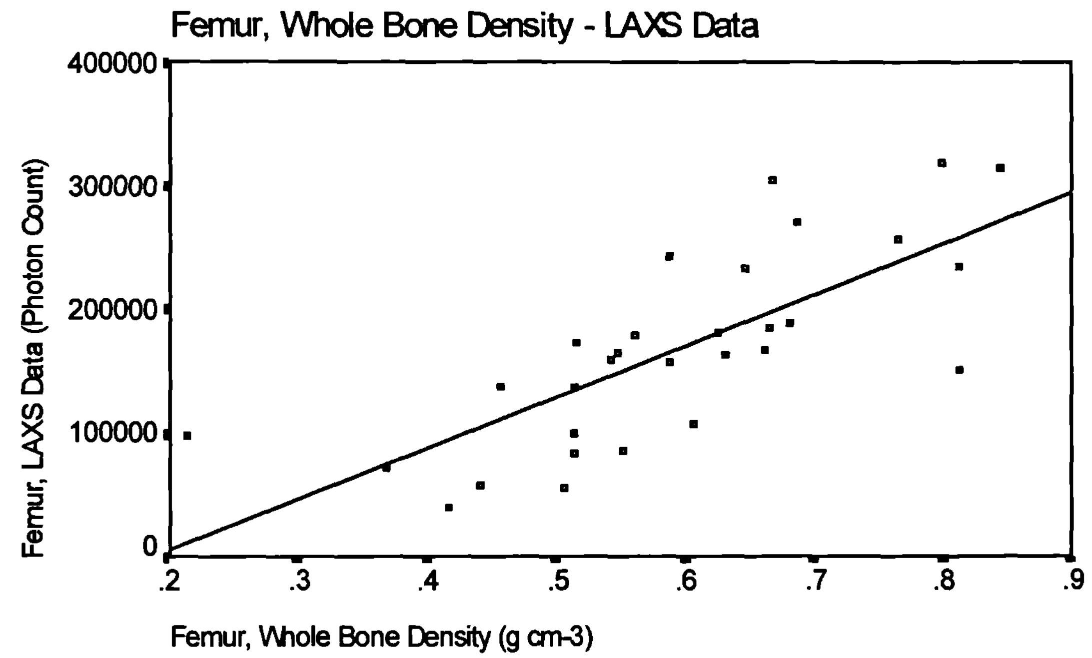


Figure 8.5.1 Femoral neck whole bone base-line density data plotted against LAXS data obtained from the femoral neck, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.75$, $p < 0.0001$. K-S (Lilliefors) $p = 0.1186$.

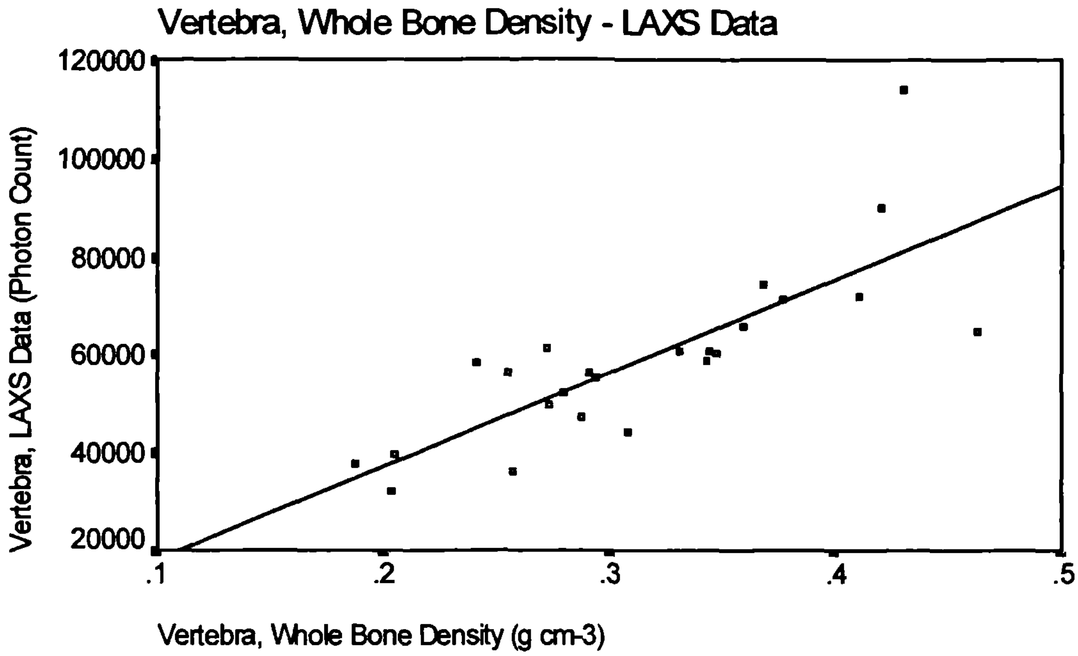


Figure 8.5.2 Vertebral body whole bone base-line density data plotted against LAXS data from the vertebral body, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.82$, $p < 0.0001$. K-S (Lilliefors) $p = 0.1059$.

The correlation coefficients between the LAXS data and the whole bone base-line density data for both the femoral neck and vertebral body were strong and highly significant.

8.5.2 Relationship between LAXS Data and Trabecular Bone Base-line Density

Figure 8.5.3 and Figure 8.5.4 show base-line trabecular bone density data for the femoral neck and vertebral body plotted against data for the same skeletal elements.

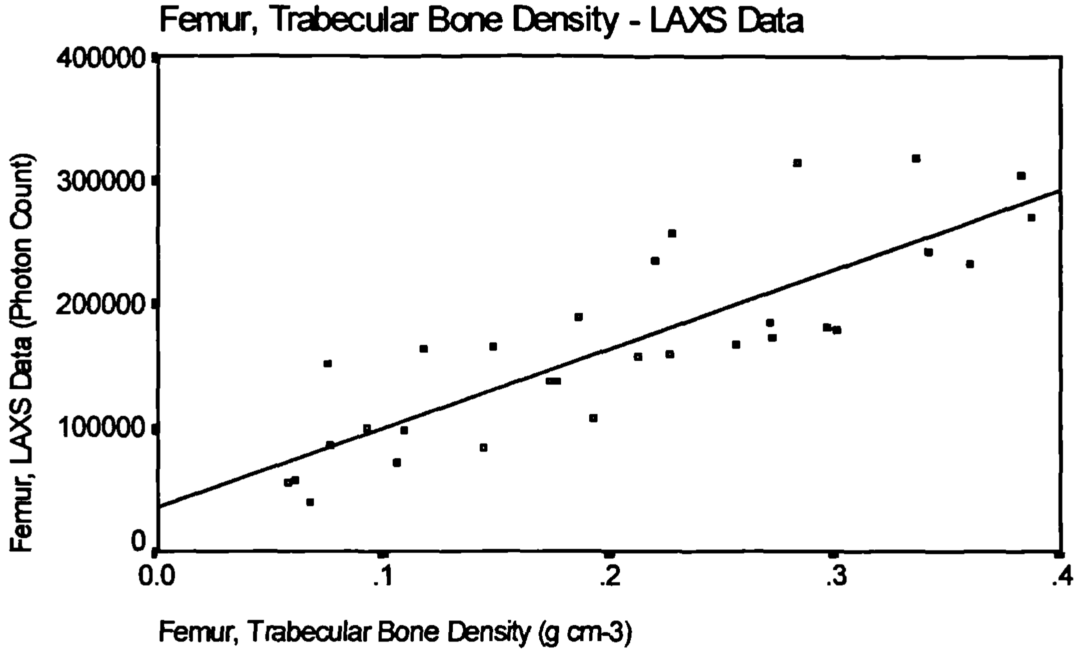


Figure 8.5.3 Femoral neck trabecular bone base-line density data plotted against LAXS data obtained for the femoral neck, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.84$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

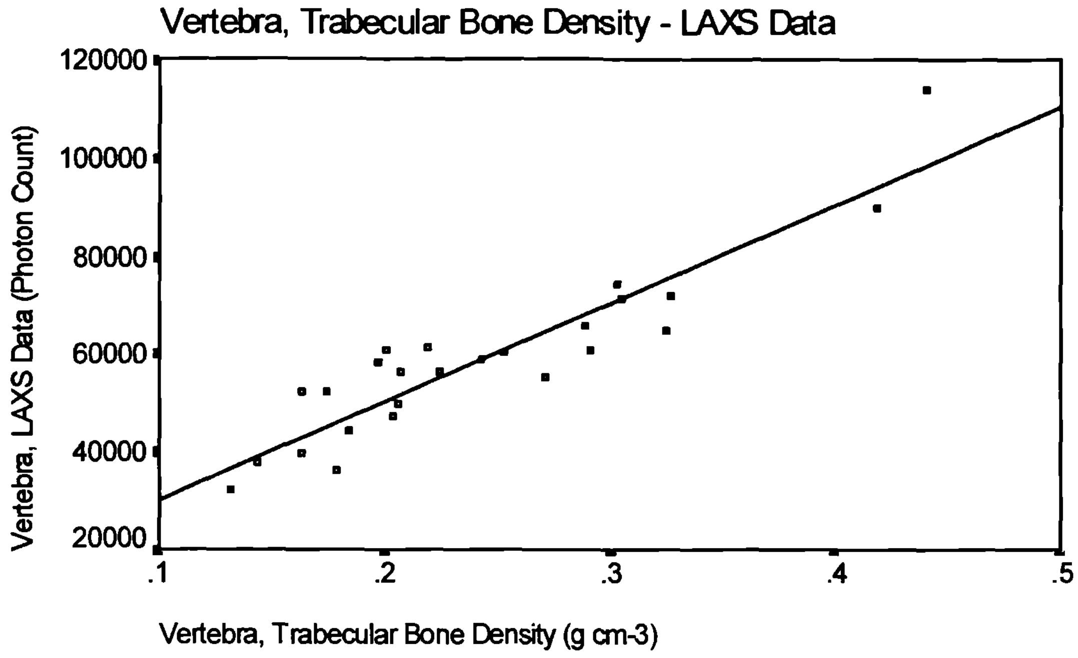


Figure 8.5.4 Vertebral body trabecular bone base-line density data plotted against LAXS data obtained for the vertebral body, with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.92$, $p < 0.0001$. K-S (Lilliefors) $p > 0.2000$.

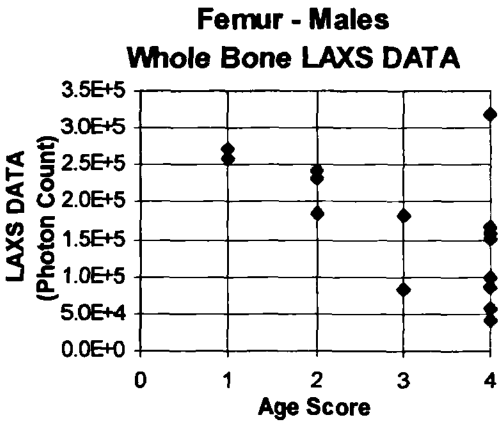
There was a strong and highly significant correlation between data produced for femoral whole bone base-line density data and LAXS analysis of the femoral neck. That for the vertebral body was a very strong positive correlation. All correlations were found to be significant.

8.5.3 Relationship between Age/Sex and LAXS Data

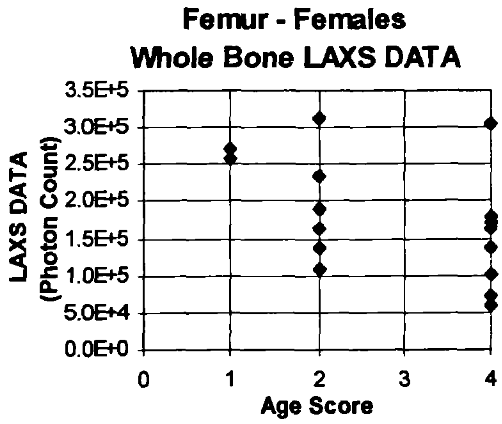
The relationship between the estimated age at death of individuals from which the sample material was obtained and the data from LAXS are examined in this section. The skeletal elements examined are the femoral neck and the vertebral body. For all skeletal elements examined, sample numbers were not large enough for rigorous statistical analysis. Table 8.5.1 shows the number of individuals in each age/sex category for each skeletal element.

Age/Sex Category	Number	
	Femoral Neck	Vertebral Body
<25	2	2
m26-35	3	2
f26-35	6	4
m36-45	2	2
f36-45	0	2
m46+	9	8
f46+	8	4
Total	30	24

Table 8.5.1 Number of femoral neck and vertebral body samples in each age/sex category for which LAXS data was obtained.

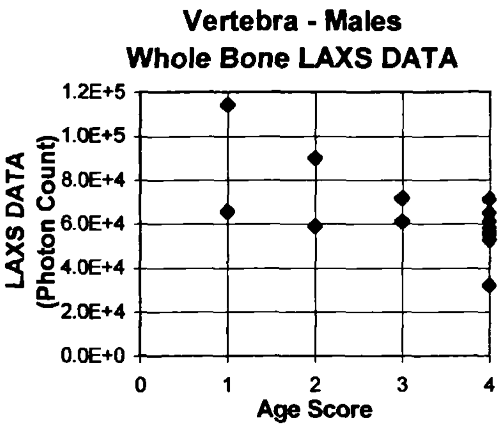


a)

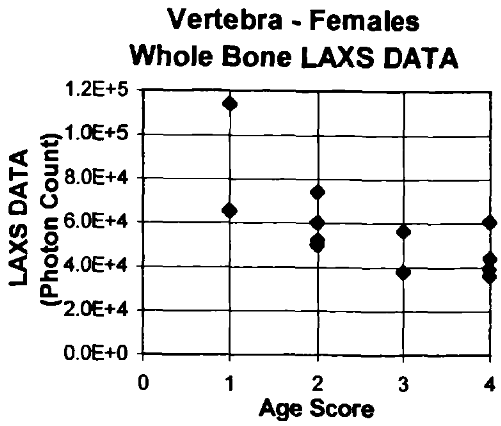


b)

Figure 8.5.5 Estimated age at death plotted against femoral neck LAXS data results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.



a)



b)

Figure 8.5.6 Estimated age at death plotted against vertebral body LAXS data results for males a) and females b). Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.

All plots showed a trend of decreasing values with age. However, age categories 15-26 years and 36-45 years generally had relatively few data points. The clearest trend occurred for the male femoral necks. However, none of the possible trends seen in this type of plot are strong.

It should be noted that the pattern in these plots could be different if sample numbers were greater.

9. Results of the Analysis of Trabecular Bone Structure

9.1 Introduction

This chapter is divided into two sections detailing the results of trabecular bone structural analysis using stereometric analysis and the Singh Index respectively. Stereometric analysis was performed on a subsample of the vertebral body slices obtained from Redcross Way and Farringdon Street using the techniques detailed in Section 7.5.3. The Singh Index was applied to radiographs of the femoral neck obtained from the Redcross Way sample material using the methods detailed in Section 7.5.1. Illustrations of femoral neck slices and the scores awarded for the Singh Index are shown in Section 7.8 (Figures 7.8.1 - 7.8.3).

9.2 Singh Index

There were thirty four femora from Redcross Way from which radiographs were obtained (Section 7.2.3) for assessment using the Singh Index using the methodology described in Section 7.5.1. Details of the scores awarded over successive scorings are given in Table 9.2.1.

Femur No.	1st Score	2nd Score	3rd Score	Final
9	B	B	B	B
11	4	3	3	3
24	4	4	4	4
26	3	3	3	3
28	4	4	4	4
32	1	3	3	3
44	3	5	4	4
46	6	5	6	6
48	B	B	B	B
52	5	5	5	5
54	6	6	6	6
56	2	5	3	3
60	5	4	5	5
62	2	2	2	2
72	4	4	4	4
89	4	5	4	4
91	3	4	4	4
100	4	6	5	5
101	5	6	5	5
114	2	5	3	3
116	1	2	2	2
118	B	B	B	B
119	4	5	5	5
120	B	B	B	B
136	3	3	3	3
137	5	6	6	6
140	5	6	5	5
150	B	B	B	B
155	3	4	4	4
159	3	3	3	3
161	5	6	5	5
165	6	6	6	6
167	4	5	5	5
175	4	6	5	5
no number	2	3	3	3

Table 9.2.1 The Singh Index score awarded to each sample on different occasions. B indicates that the femur was too broken to allow the region of interest to be properly observed. A score of 6 is given for the most complete trabecular structure and 1 for that considered to be osteoporotic.

The Singh Index requires quite a large area to be observed and in five cases the entire area needed for an observation to be made was not present. In these cases a score of B was awarded. As loss is shown in the scoring system to originate at various points of the head, neck and the top of the shaft of the femur it was felt that these should be excluded as the whole pattern of loss could not be observed.

Details of variation in scoring can be seen in Figure 9.2.1. The X-rays were re-examined and a final score was awarded to each bone, in some cases after further examination of the X-ray. It is clear however, that it would be hard for two individuals working independently to consistently award the same score. Figure 9.2.1 shows that Higher scores were given on the second scoring than the first, and this trend is reversed in the third scoring. In about 60% of the cases the same score had been awarded, and in 83% the same score had been awarded at least twice. 33% scored the same each time, 46.7% scored almost the same, 20% were more variable. Consistency in scores awarded appeared to be greatest at either extreme of the Index.

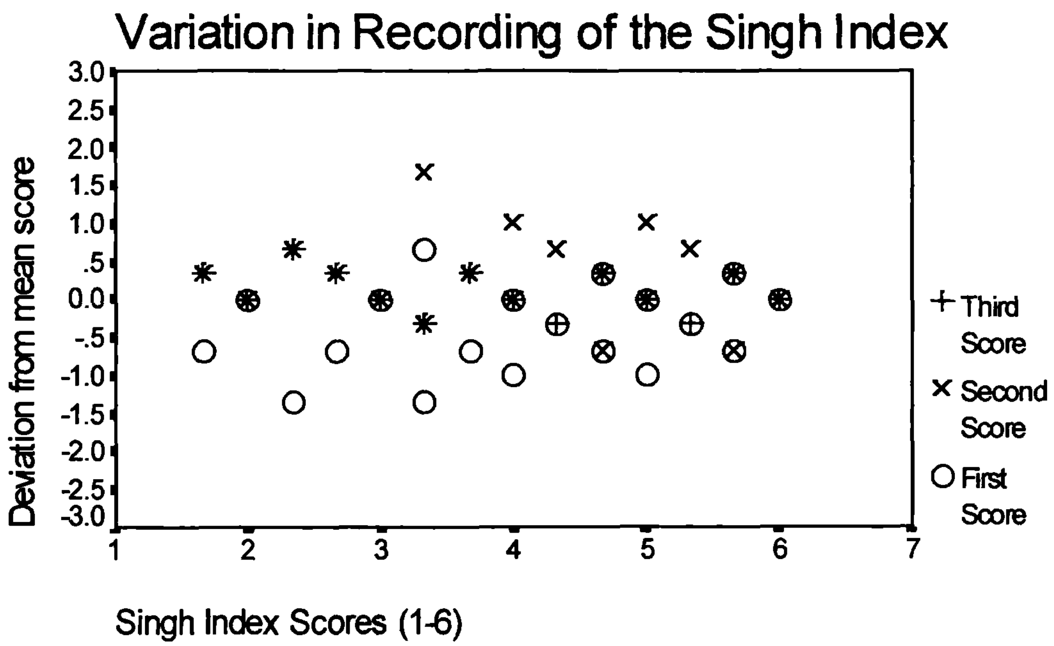


Figure 9.2.1 Deviation from the mean score awarded for the first, second and third scores given.

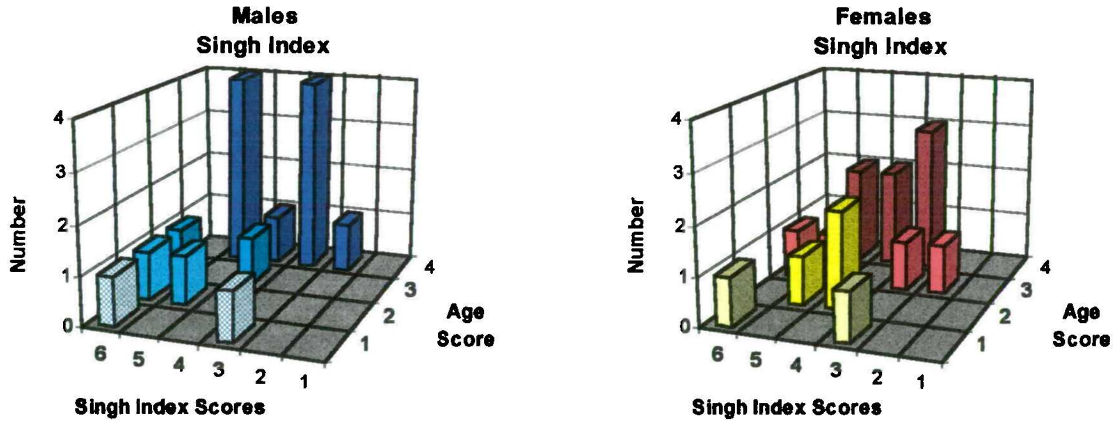
9.2.1 Relationship between Age and the Singh Index Score

The relationship between the estimated age at death of individuals from which the sample material was obtained and the data obtained from the Singh Index are examined in this subsection. The sample numbers were not large enough for rigorous statistical analyses.

Figure 9.2.2 shows the number of individuals in each age/sex category for each skeletal element.

Age Category	Number
<25	2
M 26-35	2
F 26-35	3
M 36-45	2
F 36-45	4
M 46+	10
F 46+	7
Total	30

Table 9.2.2 Number of femoral samples in age/sex category for which scores for the Singh Index were obtained.



a) b)

Figure 9.2.2 Estimated age at death plotted against the final Singh Index score results for males a) and females b). Age score 1 = 15-25 years, age score 26-35 years, age score 36-45 years and age score 4 = 46+.

The plot for the males showed a decreasing Singh Index score between age categories 26-35 years and 46+ years. No trend was observed in the plot for the females. It should be noted that the Singh Index is not a continuous measurement and therefore it is hard to detect trends.

9.2.2 The Relationship between the Singh Index and Bone Density

The results from applying the Singh Index were compared to data which had been obtained for the base-line trabecular bone density, as the Singh Index is a way of assessing the amount and quality of trabecular bone from a radiograph. Results were also compared to whole bone base-line density. The rank correlation between trabecular bone density and the scores awarded for the

Singh Index the rank correlation was $r = 0.54$, significance < 0.001 (Spearman). That between the whole bone density in the femur and the scores awarded for the Singh Index was $r = 0.59$, significance < 0.0001 (Spearman). Neither of these correlations were particularly strong, though both were significant.

9.3 Stereometry

Stereometric analysis was used to measure the three dimensional extent of trabeculae oriented in the medio-lateral and antero-posterior planes of the vertebral bodies (Section 7.5.3). Illustrations of vertebral body slices, with a range of mean trabecular length measurements are shown in Section 7.8.2 (Figures 7.8.4 - 7.8.9).

9.3.1 General Description of Structural Change.

Through visual examination of the sample slices it was possible to observe broad patterns of age- and possibly sex-related changes within the trabecular bone. Vertebral slices obtained from both males and females between 15 and 25 years of age had a densely packed and even network of trabecular bone. It was not possible to see through the bone slices, which were 5mm thick. The 26-35 year old males differed little from this (Figure 7.8.4), although some had visibly lost bone from the centre of the bone slice relative to the previous age category.

The 26-35 year old females varied. Some sample slices exhibited a similar appearance to the 15-25 year age category but others appeared to have fewer vertically (inferior-superior) oriented trabeculae (Figure 7.8.5). As the age category 15-25 is very small and of mixed sex it is not possible to say if this is bone loss or these females always had fewer trabeculae. A few had developed thicker vertical plates and comparatively thin horizontal trabeculae. In cases where such changes had occurred a greater variation in range of trabecular lengths present was observed, and it was noted that loss of trabeculae was greatest in the central region of the slice.

In the females within age category 36-45 years further bone loss was indicated (Figure 7.8.7). This originated in the central region of the bone slice and spread across the entire slice in some instances. Much thicker vertical trabecular plates could then be seen, and it was possible to trace the course of these bone elements from the superior to the inferior aspects of the vertebral body. Considerable thinning of a number of the horizontal trabeculae was also observed, and due to extensive resorption some were no longer connected at one end to the overall trabecular structure (Figure 2.3.3). Overall the trabecular lengths had a much greater range than was observable in previous age categories. The samples from the 36-45 year old males exhibited bone loss compared with the younger male age categories and, as with the females, loss that appeared to originate in the central region gradually spread across the rest of the slice. Figure 7.8.9 shows a sample from a male 36-35 years, in which there was no apparent loss from the central region of the sample slice. In some instances, it was again possible to trace vertically oriented trabecular elements from one end of the bone to the other, though this was less common. Both males and females with an estimated age at death of 36 + had a more porous appearance than younger age categories.

Severe bone loss was found in many of the females aged 46-55 years. Numerous free ending trabeculae were observable, and in all but one or two cases, it was possible to trace a significant number of trabeculae from the superior to inferior articular plates. In the males from age category 46-55 years the possibility of tracing vertically orientated trabeculae was even more common than in the male age category 36-45 years. In both the male and female age categories 46-55 years there was more variability in the horizontal strut lengths. The trabecular structure was far less densely packed and in many cases it was possible to see through the bone slices. In both the male and female age category 56+ years there was no dramatic change from the previous age category 46-55 years in both sexes, indeed all bone slices were remarkably similarly affected (Figures 7.8.6 and 7.8.8). From visual examination no difference could be discerned in thickness of vertically oriented trabeculae between the males and females in the oldest age category (56+).

Thus, the structural changes are marked by a loss of the even appearance of the trabecular bone network with thickening of the remaining vertical trabeculae and lengthening and general thinning of horizontal trabeculae. Generally these changes were more marked in females although there was variation within age categories.

9.3.2 Grouped Trabecular Length Measurements

All length measurements were grouped according to age/sex and the grouped data analysed. Summary data obtained for each age/sex category is provided in Table 9.3.1.

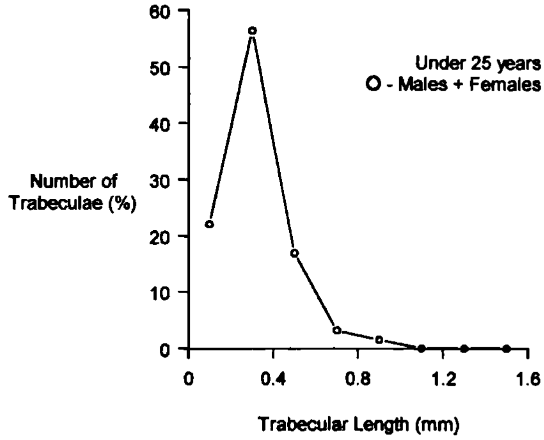
	M&F	Male				Female			
	>15-25	26-35	36-45	46-55	56+	26-35	36-45	46-56	56+
Number	6	10	10	12	6	10	10	9	6
Count	598	898	1000	1155	595	958	945	879	583
Max	0.963	0.892	1.513	4.793	4.553	3.612	4.497	4.387	4.793
Mode	0.225	0.214	0.411	0.454	0.424	0.371	0.357	0.583	0.626
Median	0.275	0.282	0.520	0.717	0.863	0.435	0.709	0.820	0.882
Mean	0.312	0.306	0.555	0.856	0.985	0.656	0.901	0.937	1.044
Variance	0.021	0.019	0.049	0.306	0.294	0.398	0.453	0.295	0.345
St. Dev.	0.146	0.137	0.222	0.554	0.542	0.631	0.673	0.543	0.588

Table 9.3.1 Summary information on the lengths of horizontal trabeculae in mm obtained from analysis of data obtained during stereometry analysis.

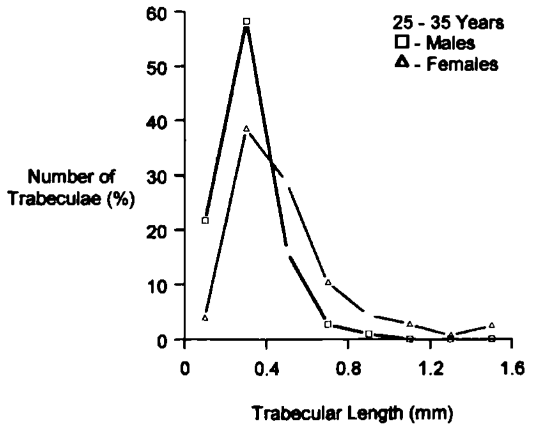
The trabecular length measurements obtained for each individual were divided into one of twenty five categories according to length, from 0.2 mm - 5.0 mm. Analysis of the trabecular strut length data for each individual enabled differences in trabecular structure between the different age/sex categories to be observed.

The results obtained from the grouping of trabecular strut lengths were analysed both for each skeleton sampled individually (Figure 9.3.2 a-e) and collectively for each of the age categories

(Figure 9.3.1). The Kolmogorov-Smirnov test was used to check that the data within each category was normally distributed, which was the case for all age categories. It was therefore appropriate to use the t-test for all comparisons. This test is based on the maximum differences between cumulative distributions of two populations. The magnitude of the test statistic provided by the t-test provides a quantitative measure of the levels of significance of the difference between two populations. The meaning of the test statistic in terms of 'significance' is summarised in Table 8.2.2. These descriptions of significance are maintained throughout this chapter for the t-test. Statistical tests to determine levels of difference between data derived from each age/sex category were performed.



a)



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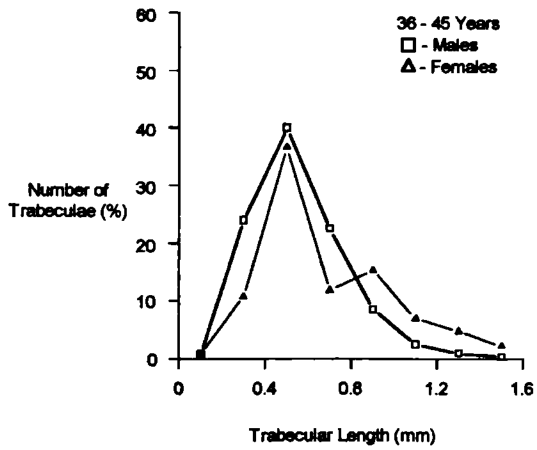
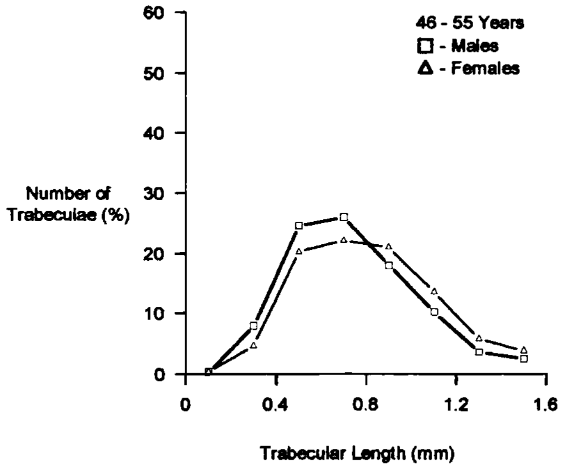
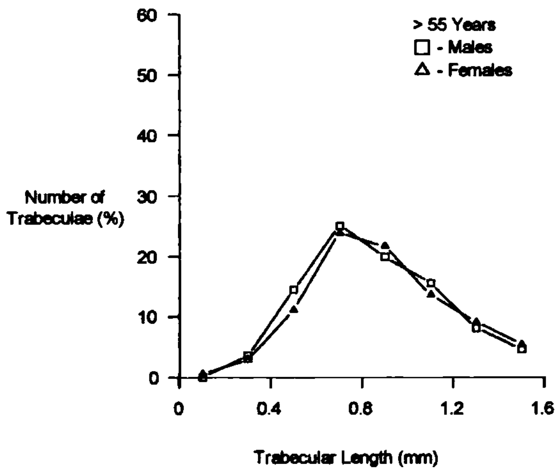


c)



d)



e)

Figure 9.3.1 a, b, c, d, e Distribution of all measured trabecular lengths placed into bin widths of 0.2 mm, for a) 15-25 years, unsexed; b) 26-35 years males and females; c) 36-45 years males and females; d) 46-55 years males and females; e) 56+ years males and females.

15-25 Years Figure 9.3.1 (a)

The spread of the distribution of trabecular lengths displayed by the youngest age category was extremely narrow, both for individual and grouped results, with all observed measurements falling in the first five trabecular length groups (0.2 mm - 1 mm). 56% of the data fell into the group 0.4mm. The mode fell at the lower end of the trabecular length measurements.

Males 26-35 Years Figure 9.3.1 (b)

The data collected from the individuals placed in this age category was almost identical to that from the age category 15-25 years. The spread of distribution was again confined to the first five trabecular length groups, with the greatest concentration in the trabecular length group 0.4 mm within this age/sex category 58% of the trabeculae fell into this length group.

Females 26-35 Years Figure 9.3.1 (b)

A marked difference in the pattern of distribution was observed in this age/sex category. Trabecular length measurements were spread across 19 of the groups (0.2 mm - 3.8 mm). The largest concentration of trabecular length measurement (38.5%) still fell into the 0.4 mm grouping. However, most of the measurements recorded fell at the lower end of the range, 81.5% fall between 0.2 mm and 0.8 mm. A wider spread of measurements with a longer tail was seen.

Males 36-45 Years Figure 9.3.1 (c)

There were changes in trabecular distribution between this and the previous age/sex category. In this category the data fell across the first 8 length groups (0.2 mm - 1.6 mm). The highest concentration of measurements, 40% was seen to fall in the 0.6 mm trabecular length group. The mode had increased, and the spread was wider with lower peaks of occurrence.

Females 36-45 Years Figure 9.3.1 (c)

The range of trabecular length groups into which data fell had increased to 23 and the mode to 0.6 mm. 36.6% of the measurements fell within this range, with the majority of data (81.6%) between trabecular length group 0.4 mm and 1.2 mm.

Males 46-55 Years Figure 9.3.1 (d)

There was a greater spread in the distribution of trabecular length measurements. Trabecular length measurements between 0.2 mm - 4.8 mm were recorded, (although there were no measurements recorded for the category 4.6 mm). The highest concentration of measurements fell in the category 0.8 mm (26%), and 86% of the trabecular lengths fell between 0.4 mm and 1.2 mm.

Females 46-55 Years Figure 9.3.1 (d)

For the first time the averaged trabecular length distribution were seen to be slightly less than that observed for males, data fell within the range 0.4 mm - 4.4 mm. As previously the distribution was not continuous, there was no data recorded for the category 4.2 mm. As in the male sample of this age the greatest concentration of trabecular length measurements fell in the group 0.8 mm. However, there was a marginally larger spread of measurements, with 87% falling between 0.4 mm and 1.4 mm.

Males 56+ Figure 9.3.1 (e)

The spread of measurements was slightly narrower than in the previous age category, with trabecular length measurements falling between 0.4 mm and 4.6 mm. The spread was not continuous, no measurements between 3.8 mm and mm 4.4 were recorded. The greatest concentration of measurements occurred at 0.8 mm, 86% fell between 0.4 mm and 1.4 mm.

Females 56+ Figure 9.3.1 (e)

The overall spread of trabecular length measurements was larger than in the previous age category. The spread fell between 0.2 mm and 4.6 mm, but was not continuous with no measurements recorded for the trabecular length groups 4.2 and 4.4 mm. The mode occurred in the group 0.8 mm, and 87% of the measurements fell between 0.4 mm and 1.6 mm.

9.3.3 Individual mean trabecular lengths for each age/sex category

The mean trabecular length for each vertebra was plotted to show the variation both within each of the age and sex categories and between categories (Figure 9.3.2). Summary information including overall category means and standard deviations were calculated (Table 9.3.1.) The males had a shorter mean trabecular length for each age category; but the difference between means for males and females decreases with age. Overall the means and ranges of trabecular length increased with age for both males and females.

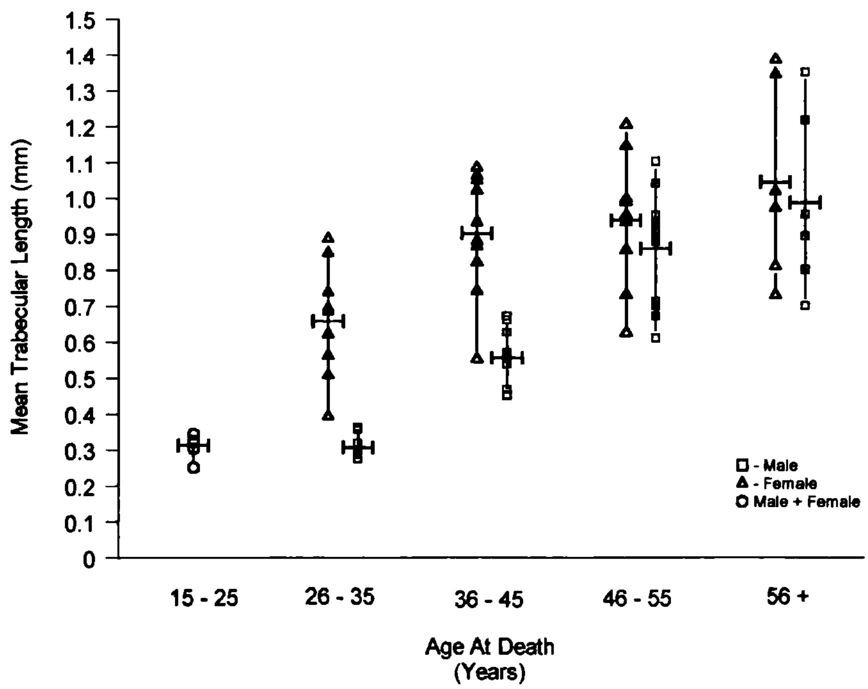


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Figure 9.3.2 Mean trabecular length from the vertebral body plotted against each age/sex category for the subsample. The horizontal bar represents the mean value for each category. The vertical bars mark the range of mean values for individuals in each age category.

The Spearman rank correlation between sex/age and mean trabecular length are given below.

Males

Rank correlation coefficient (Spearman) $r = 0.89$, significance < 0.0001.

Females

Rank correlation coefficient (Spearman) $r = 0.76$, significance < 0.0001.

There was a strong positive correlation which was significant between estimated age at death in the males and females and mean trabecular strut length.

Mixed sex category 15-25 Years (Figure 9.2.2)

The range of individual means was very small and the overall mean trabecular length was low.

Females 26-35 Years

There was a wider range of trabecular lengths and the range of means found for individuals sampled than in the previous category.

Males 26-35 Years

The males in this category are almost identical to the mixed sex category 15-25 years.

Males 36-45 Years

The range over which data fell was greater than in the previous male category, but still much smaller than for the females of the same age.

Females 36-45 Years

The range of data was similar to the previous female category. However, the overall mean for this age category had increased.

Males 46-55 Years

The range data fell is far wider that in previous male categories, though still not as great as that in the female category of the same age.

Females 46-55 Years

The range and overall mean had increased slightly from the previous female age category.

Males 56+

The range of individual means was much wider than in the previous age category, and was similar to that of the females in the same age category.

Females 56+

The range and overall mean had increased slightly from the previous female age category.

Overall the range and mean for both males and females increased with age, though this occurred sooner in females. The females always had a higher overall mean than the males.

9.3.4 Levels of Difference between the Individual Data in Each Age/Sex Category

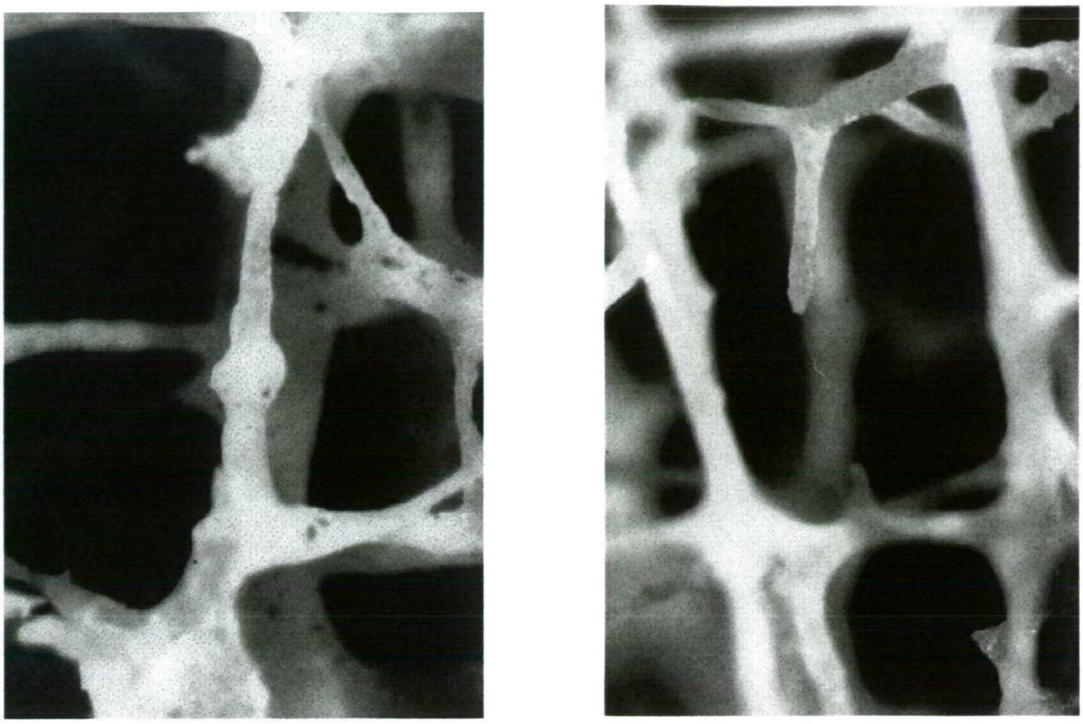
The statistical analyses to test the difference between the various age/sex categories in the 'sub sample' on which stereometric analyses were performed are given in Table 9.3.2. The mixed sex 15-25 years age category were highly significantly different to all other categories except the male age category 26-35 years. The females 26-35 years were very significantly different from all other age/sex categories, apart from females 36-45 years where they were seen to be significantly different and males 26-35 years where they were highly significantly different. All the female age categories were observed to be highly significantly different from males 26-35 and 36-45 year age categories. The males 56+ years were seen to be very significantly different from the female categories 26-35 and females 36-45 years. Overall the differences between the males and females and between adjacent age categories decreases with age.

	M+f15-25	F26-35	F36-45	F46-55	F56+		M26-35	M36-45	M45-55	M56+
15-25	*									
F 26-35	<0.0001	*								
F 36-45	<0.0001	0.0031	*							
F46-55	<0.0001	0.0024	0.6600	*						
F 56+	0.0012	0.0180	0.0180		*					
M 26-35	0.7100	<0.0001	<0.0001	<0.0001	0.0012		*			
M 36-45	<0.0001	0.0810	0.0001	0.0002	0.0076		<0.0001	*		
M46-55	<0.0001	0.0055	0.5400	0.3100	0.1700		<0.0001	<0.0001	*	
M 56+	0.0013	0.0220	0.4800	0.6900	0.7100		0.0012	0.0093	0.2900	*

Table 9.3.2 T-test for levels of significance between individual mean data for all age/sex categories. The shaded cells are statistically significant.

9.3.4.1 Occurrence of Fractures Repaired by Microcallus and Free-ends

Vertebral sample slices from the subsample were examined using light microscopy to detect the presence of free ending trabeculae and microcallus fractures (Section 7.5.2). Neither feature was observed in samples taken from individuals below the age of 36. A microcallus fracture and free-ending area of trabecular bone typical of those seen during examination of the sample slices are shown in Figure 9.3.3.



a) b)

Figure 9.3.3 a) A microcallus fracture (centre of field) seen in the sample material b) A typical free ending trabeculae (centre of field). Field width is approximately 2.5 mm.

As can be seen in Table 9.3.3 the incidence of microcallus is very low, it is not possible to read too much into this data. Free ending trabeculae were seen to be more frequent in the females than the males sampled. Microcallus fractures were seen to appear in females at an earlier age than males, but by the age category 56+ years the frequency of appearance was identical for both males and females.

	Females			Males		
Age Category	Total sample	Free ends	Microcallus	Total sample	Free ends	Microcallus
36-45	10	4	0	10	1	0
46-55	9	4	1	12	4	0
56+	6	4	2	6	4	1

Table 9.3.3 The percentage of the total sample of males and females in each age category in which free ends and microcallus fractures were observable.

9.4 Relationship Between Structure and Density

Mean trabecular strut length for the vertebrae obtained using the methodology outlined in Section 7.5.3 was compared to base line bone density (Section 7.3.1) for whole and trabecular bone. The trabecular bone and its micro-architectural arrangement can be observed in Figures 7.8.4 to 7.8.9. Mean trabecular strut length is given for each slice in the table below, along with whole and trabecular bone density data obtained for the slice.

A moderate negative correlation which was significant was found between mean trabecular strut length and both whole bone base-line density and trabecular bone base line density (Figure 9.4.1 and Figure 9.4.2). In neither case was the correlation very strong, but it was slightly stronger for the trabecular bone density.

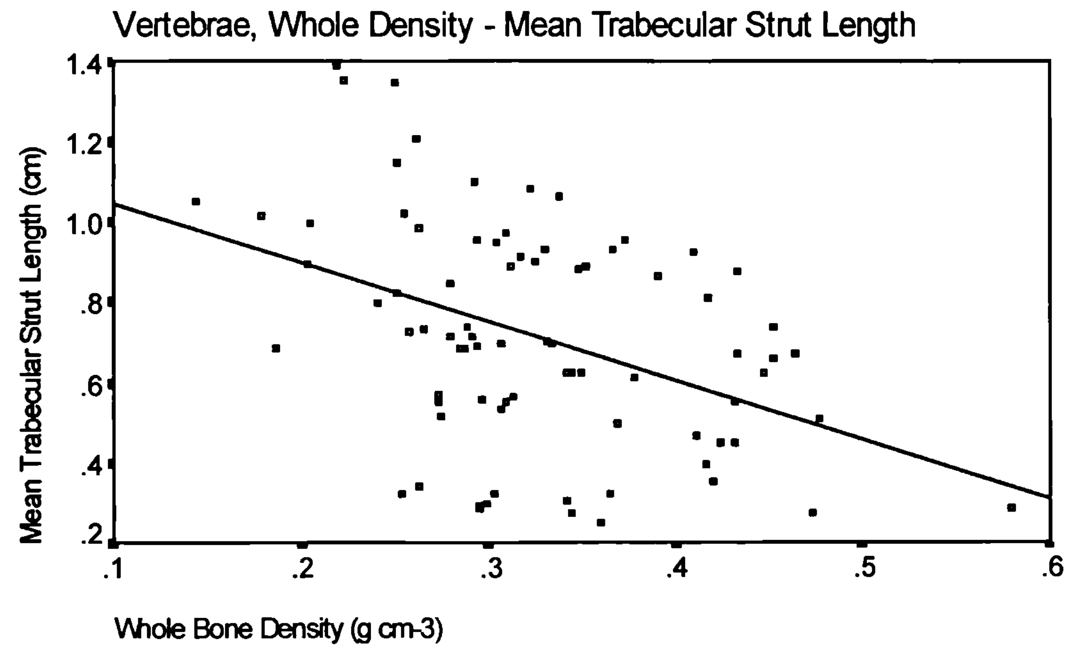


Figure 9.4.1 Vertebral body whole bone density plotted against mean trabecular strut length with line of least square regression plotted. Correlation coefficient (Pearson) $r = -0.40$, $p < 0.0001$. K-S (Lilliefors) >0.2000.

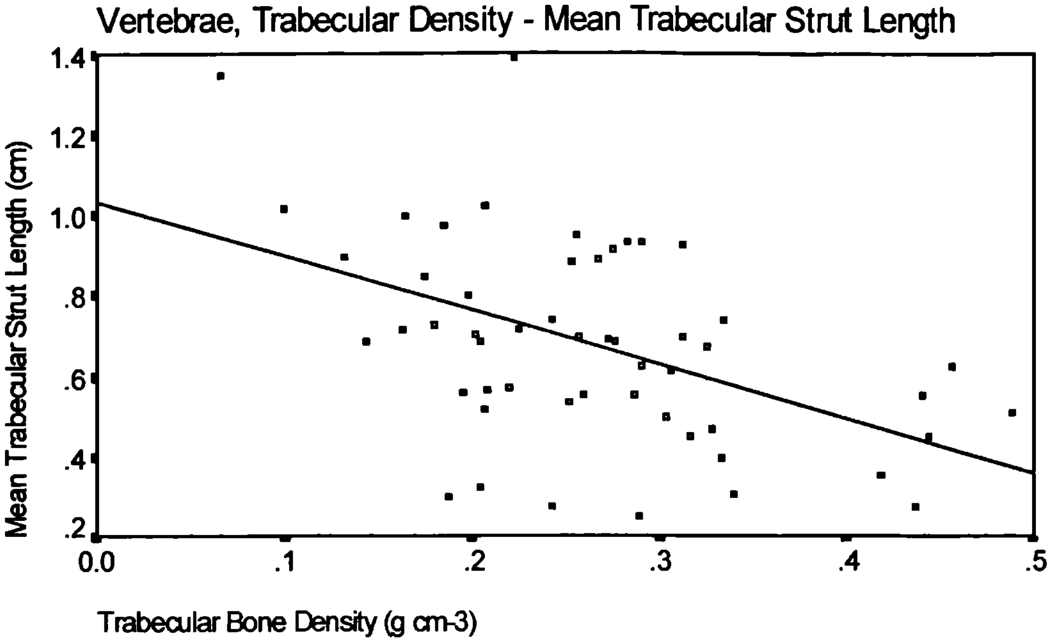


Figure 9.4.2 Vertebral body whole bone density plotted against mean trabecular strut length with line of least square regression plotted. Correlation coefficient (Pearson) $r = -0.50$ $p < 0.0001$. K-S (Lilliefors) > 0.2000.

9.4.1 Relationship between Bone Density and Microcallus Fractures and Free-ends

Base-line density data was plotted for both whole and trabecular bone, with samples in which microcallus fracture (Figure 9.4.3 and Figure 9.4.4) were indicated with a different symbol. Figure 9.4.5 and Figure 9.4.6 are plots for base line density data with samples in which free ends were observed marked by a different symbol. Samples examined were those from the subgroup which were examined stereometrically.

Numbers of samples in which microfracture callus was observed were small. However, in the case of whole bone density these samples can be seen to fall at the lower end of the density range. In the case of trabecular bone density, samples in which a microfracture callus was observed are spread more widely across the range of densities.

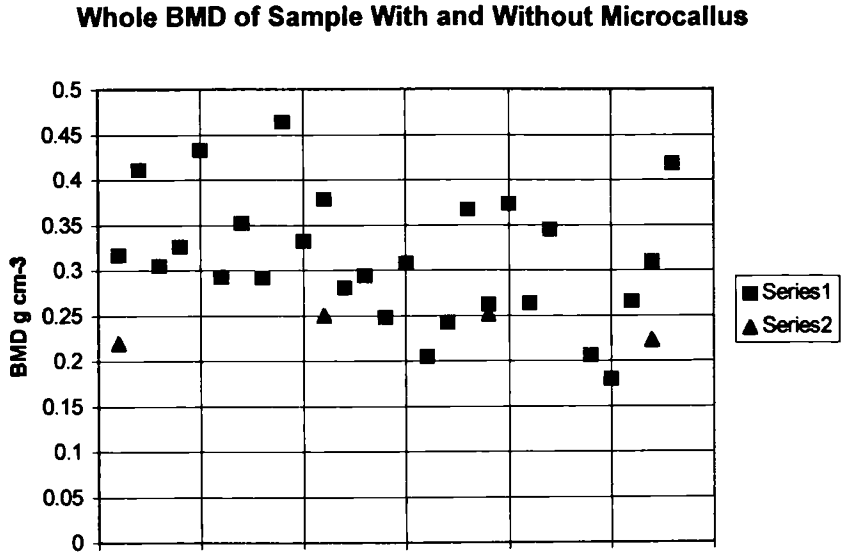


Figure 9.4.3 Whole bone base line density data plotted for male and female age categories 46-55 years and 56+ years. Series 2 are samples in which microcallus fracture was observed. The x axis is the order in which sample data obtained.

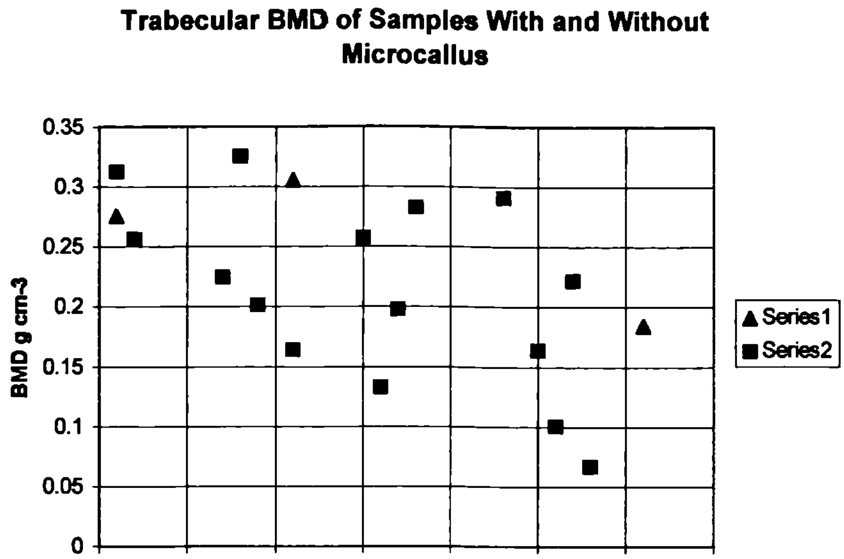


Figure 9.4.4 Trabecular bone base line density data plotted for male and female age categories 46-55 years and 56+ years. Series 1 are samples in which microcallus fracture was observed. The x axis is the order in which sample data obtained.

Free-ending trabeculae were observed in a greater number of samples than microcallus fractures. The distribution of these samples in Figure 9.4.5 was at the lower end of the range of whole bone base-line densities recorded, though there was an overlap in the data. In the case of trabecular bone base line density data there was no pattern to the distribution of data.

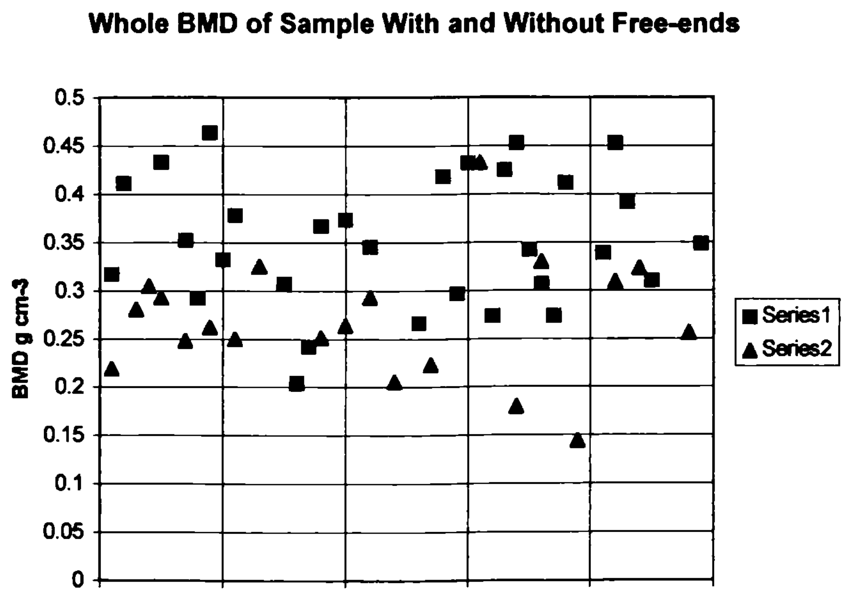


Figure 9.4.5 Whole bone base line density data plotted for male and female age categories 36-45 years, 46-55 years and 56+ years. Series 2 are samples in which free-ending trabeculae were observed. The x axis is the order in which sample data obtained.

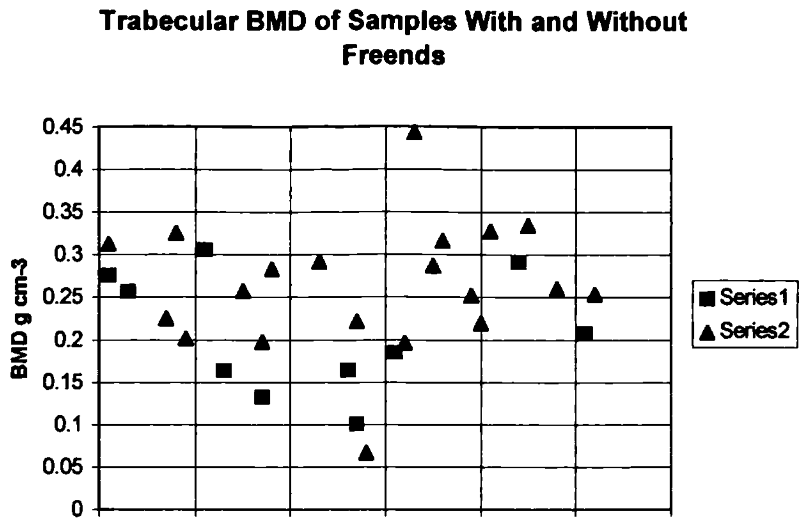


Figure 9.4.6 Trabecular bone base line density data plotted for male and female age categories 36-45 years, 46-55 years and 56+ years. Series 1 are samples in which free-ending trabeculae were observed. The x axis is the order in which sample data obtained.

10. Cortical Bone Loss

10.1 Introduction

A number of measures of cortical bone have been applied in past studies of archaeological bone material (Section 5). In the present study various approaches to cortical bone measurement were examined. This chapter is divided into sections detailing the results of each type of cortical bone analysis performed on the sample material. The main headings under which the results are presented are as follows.

a) cortical thickness;
b) cortical index;
c) cortical area.

Each measurement was carried out on precisely the same area of the femoral neck which had been analysed using the previous methods. The relationship of each of these cortical measures to one another is examined (Section 10.5). Cortical bone and base-line bone density are also compared (Sections 10.6, 10.7, 10.8), and the relationship between estimated sex/age at death and cortical bone is considered (Section 10.9). Illustrations in Section 7.8 (Figures 7.8.1 - 7.8.3), show the range of cortical bone thickness observed in femoral neck sample slices. Tables below detail the results of each technique applied to the slices.

10.2 Cortical Thickness

Thirty one femoral necks were available from Redcross Way for analysis of cortical the cortical thickness. The cortical thickness was calculated using the methodology outlined in Section 7.6.2. Table 10.2.1 gives details of the mean cortical thickness obtained from each femoral neck..

Cortical Thickness					
Male aged	**cm**	**Female aged**	**cm**	**Ambiguous**	**cm**
15-25	0.1094	15-25	0.1756	46+	0.0776
26-35	0.1224	26-35	0.1531		
26-35	0.1271	26-35	0.1771		
26-35	0.0991	26-35	0.1490		
36-45	0.1115	26-35	0.1183		
36-45	0.1259	36-45	0.1583		
46+	0.1610	36-45	0.1764		
46+	0.1618	36-45	0.1495		
46+	0.1764	46+	0.1618		
46+	0.1455	46+	0.0824		
46+	0.1028	46+	0.1279		
46+	0.2211	46+	0.1013		
46+	0.1464	46+	0.0644		
46+	0.1483	46+	0.0918		
46+	0.1269	46+	0.1056		
		46+	0.1659		

Table 10.2.1 Mean cortical thickness in cm for each individual (age category in years) sampled from Redcross Way.

The male and female samples <26 years are listed separately in Table 10.2.1 as it was felt that sex could be assigned with reasonable confidence. However, in later plots males and females are plotted together as there is more uncertainty over sexing of younger individuals and there was only one individual in each category.

10.3 Cortical Index

Thirty one femora were available from Redcross Way for analysis of the cortical index. The cortical index was calculated using the methodology outlined in Section 7.6.3. Table 10.3.1 gives results of cortical index calculations from the femoral neck.

Cortical Index					
Male	index	Female	index	Ambiguous	index
15-25	7.6590	15-25	12.4333	46+	8.1321
26-35	6.9181	26-35	11.8893		
26-35	9.6527	26-35	19.9266		
26-35	5.8645	26-35	10.7091		
36-45	11.2790	36-45	10.4710		
36-45	9.7160	36-45	15.7603		
46+	6.4278	36-45	3.6499		
46+	6.9075	46+	7.9157		
46+	17.6471	46+	12.2766		
46+	8.1412	46+	10.4396		
46+	15.4934	46+	5.9823		
46+	7.0483	46+	9.5544		
46+	6.6592	46+	7.7958		
46+	9.4769	46+	12.1212		
46+	9.9572	46+	16.6158		

Table 10.3.1 Individual cortical index scores calculated for the femoral neck (Redcross Way) (age given in years).

10.4 Cortical Area

Thirty one femora were available from Redcross Way for analysis of the cortical area. The cortical area was calculated using the methodology outlined in Section 7.6.4. Table 10.4.1 gives results of cortical area calculations from the femoral neck.

Cortical Area					
Male	**cm^{-2}**	**Female**	**cm^{-2}**	**Ambiguous**	**cm^{-2}**
15-25	1.340	15-25	1.648	46+	1.195
26-35	1.780	26-35	1.233		
26-35	1.484	26-35	1.269		
26-35	1.352	26-35	1.500		
36-45	1.900	36-45	1.408		
36-45	1.282	36-45	1.950		
46+	1.246	36-45	1.284		
46+	1.438	46+	0.980		
46+	1.805	46+	0.984		
46+	1.352	46+	1.453		
46+	3.000	46+	1.313		
46+	1.531	46+	1.347		
46+	1.776	46+	0.935		
46+	2.133	46+	2.001		
46+	1.715	46+	1.850		

Table 10.4.1 Individual cortical area cm^{-2} calculated for each individual sampled from Redcross Way (age given in years).

10.5 The Relationship between the Different Measures of Cortical Bone.

Cortical index, cortical area and cortical thickness were compared for the same sample by scatter diagrams with the line of least square regression plotted. The correlation coefficient between the cortical bone measurements was calculated.

In all cases, the correlation was very weakly positive, and not significant. There seems to be no relationship between the different methods of cortical bone measurements in this study group. The outlier in the plots came from the same sample, a male in the age category 46+ years.

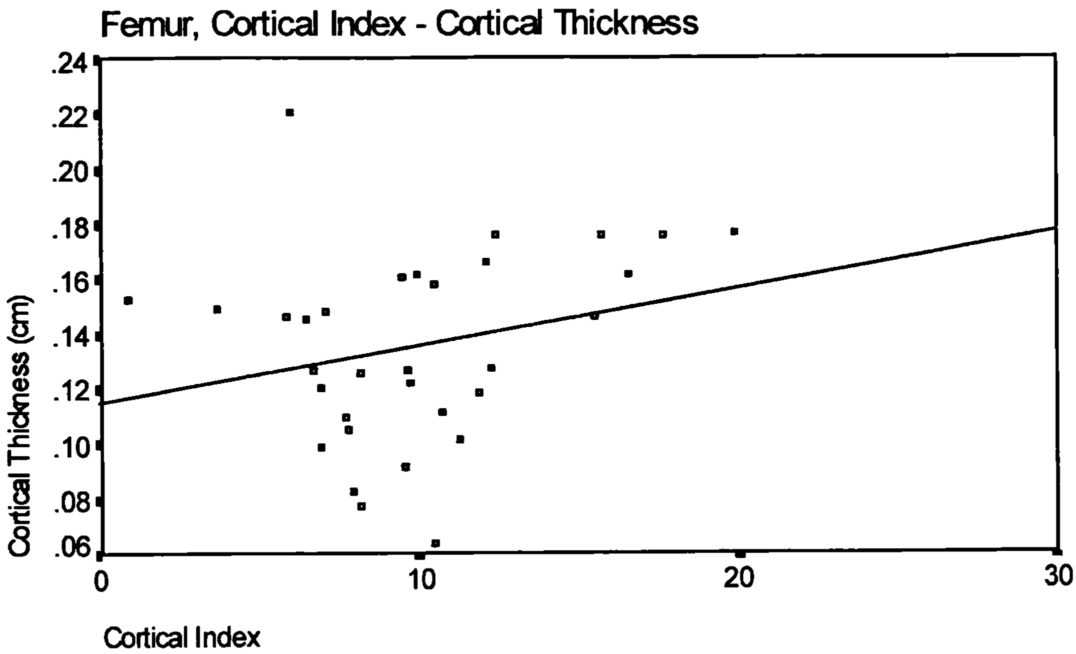


Figure 10.5.1 The cortical index plotted against the cortical thickness with line of least square regression plotted. Correlation coefficient (Pearson) $r = 0.25$, $p = 0.175$. K-S (Lilliefors) $p > 0.2000$.

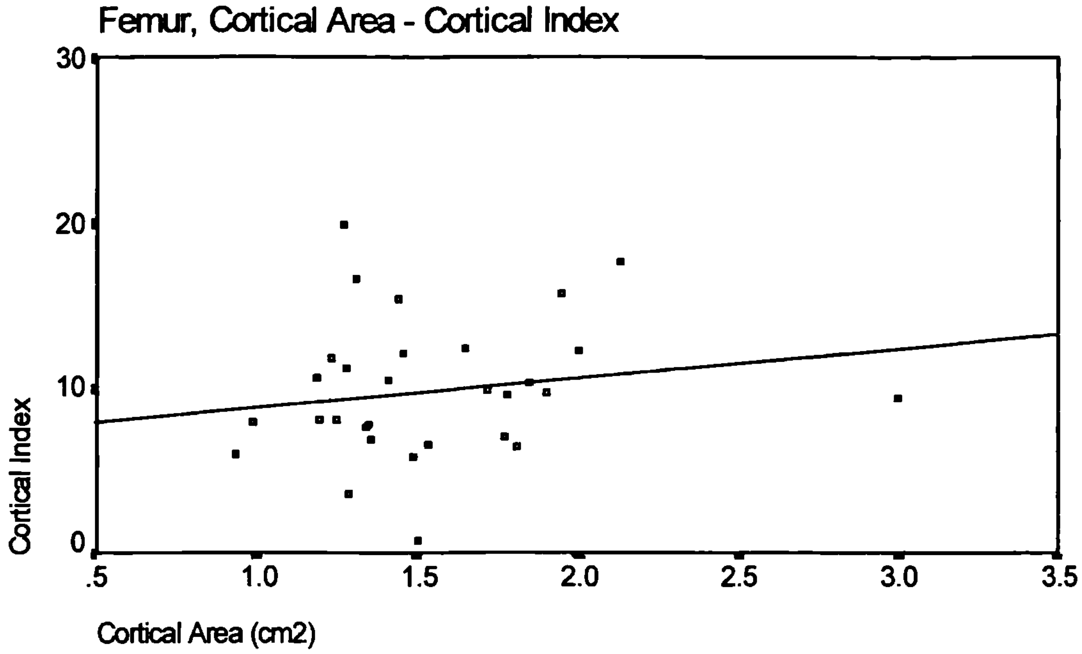


Figure 10.5.2 The cortical area plotted against the cortical index with least square regression line plotted. Correlation coefficient (Pearson) r = 0.17, p = 0.348. K-S (Lilliefors) p >0.2000.

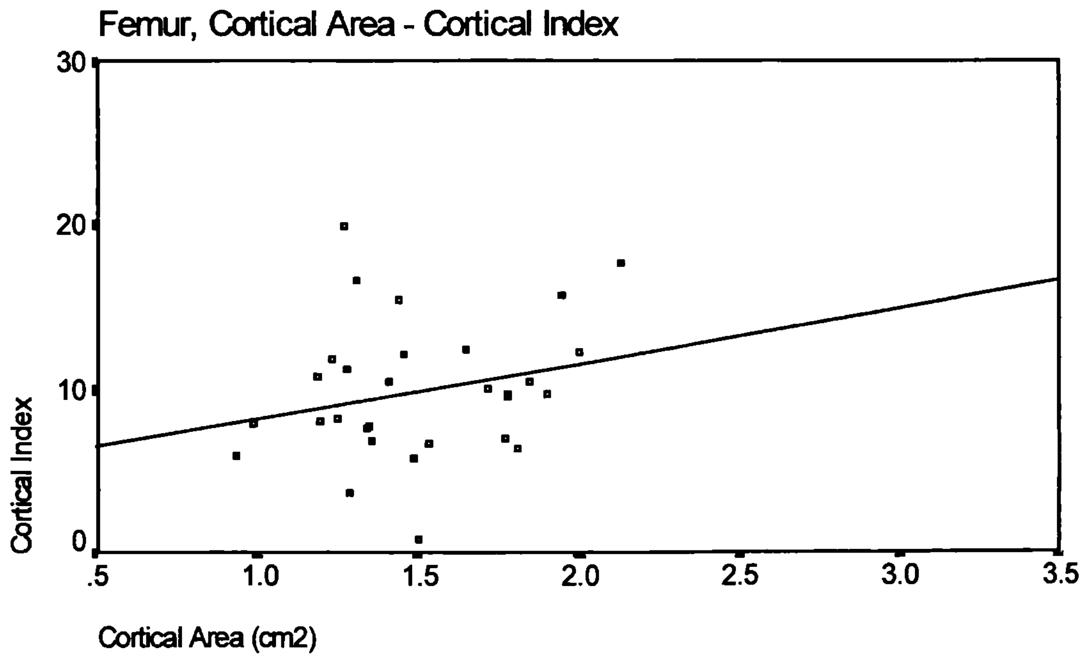


Figure 10.5.3 The cortical area plotted against the cortical index with outlier removed. The least square regression line is plotted. Correlation coefficient (Pearson) r = 0.25, p = 0.184. K-S (Lilliefors) p >0.2000.

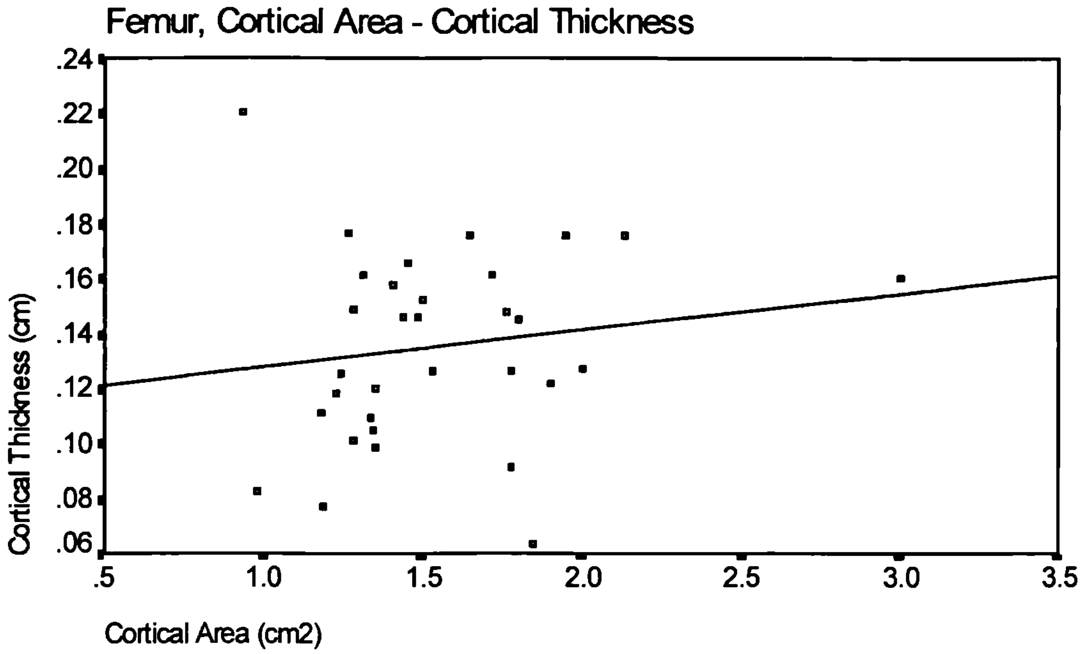


Figure 10.5.4 Cortical area plotted against cortical thickness with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.15$, $p = 0.420$. K-S (Lilliefors) >0.2000. K-S (Lilliefors) p >0.2000.

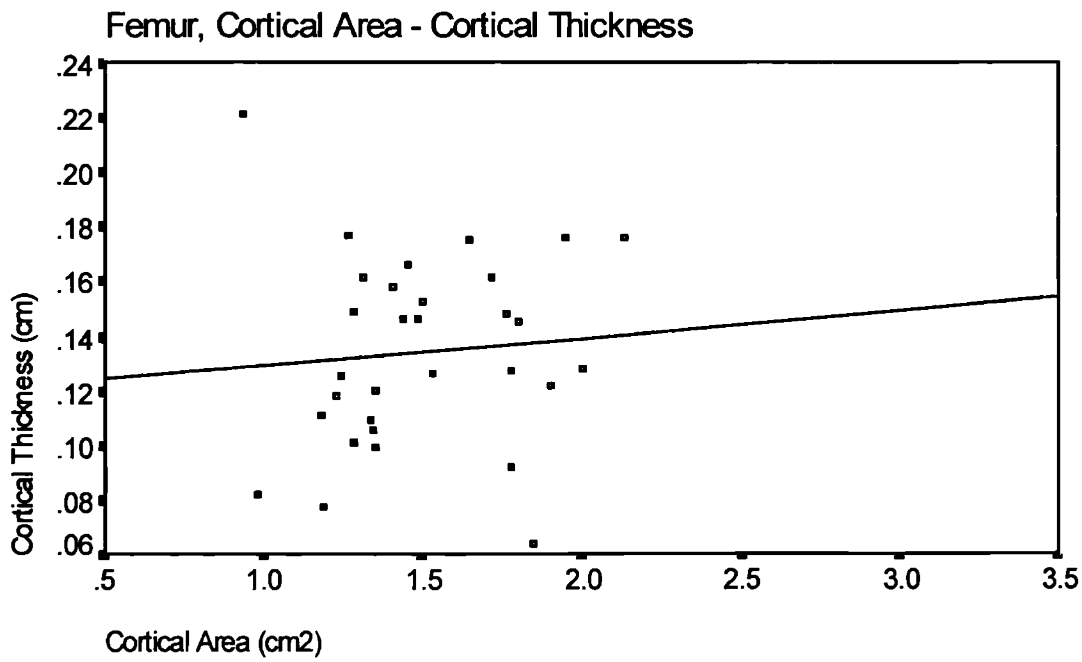


Figure 10.5.5 Cortical area plotted against cortical thickness with outlier removed. The least square regression line is plotted. Correlation coefficient (Pearson) $r = 0.08$, $p = 0.652$. K-S (Lilliefors) p >0.2000.

10.6 Relationship between Cortical Thickness and Base-line Bone Density

These two aspects of bone and their relationship were examined as they are two of the most commonly used techniques in the assessment of bone loss in archaeological bone previously used (Section 5).

10.6.1 Femoral Neck Whole Bone Density

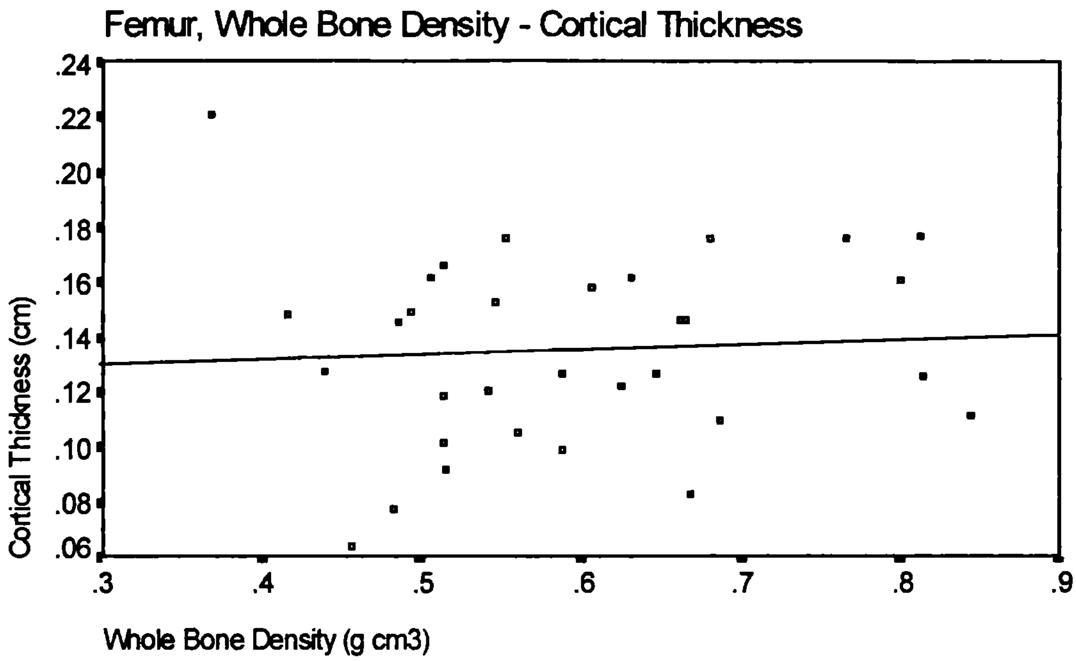


Figure 10.6.1 Femur whole bone density plotted against cortical thickness with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.06$, $p = 0.743$. K-S (Lilliefors) $p > 0.2000$.

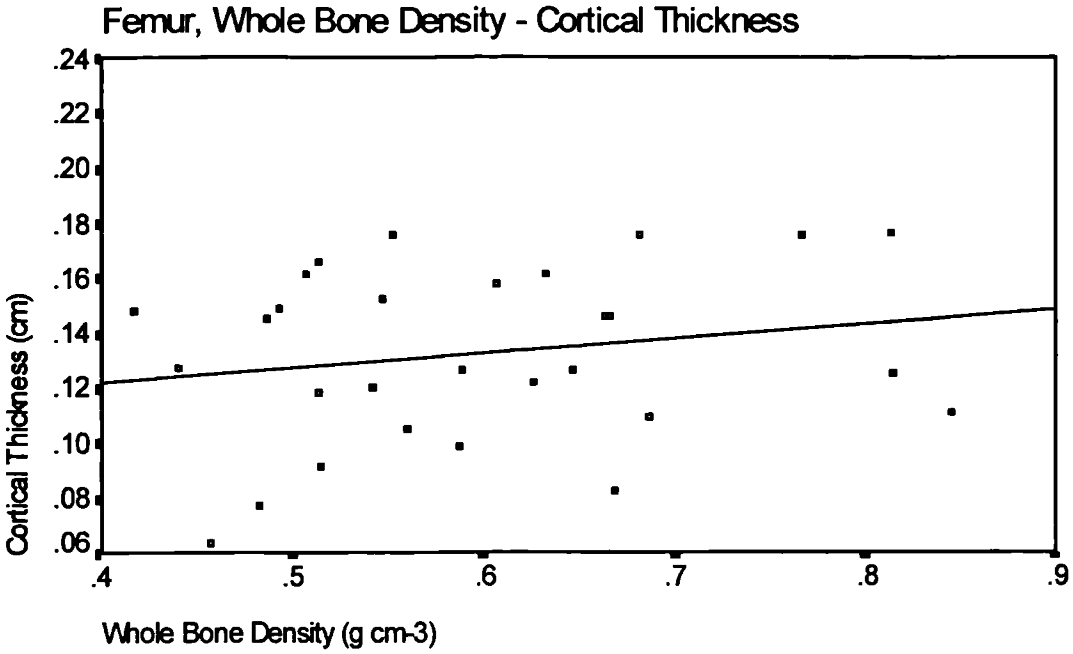


Figure 10.6.2 Femur whole bone base-line density data plotted against cortical thickness with outlier removed. The least square regression line is plotted. Correlation coefficient (Pearson) $r = 0.25$, p = 0.173. K-S (Lilliefors) > 0.2000.

10.6.2 Trabecular Bone Density

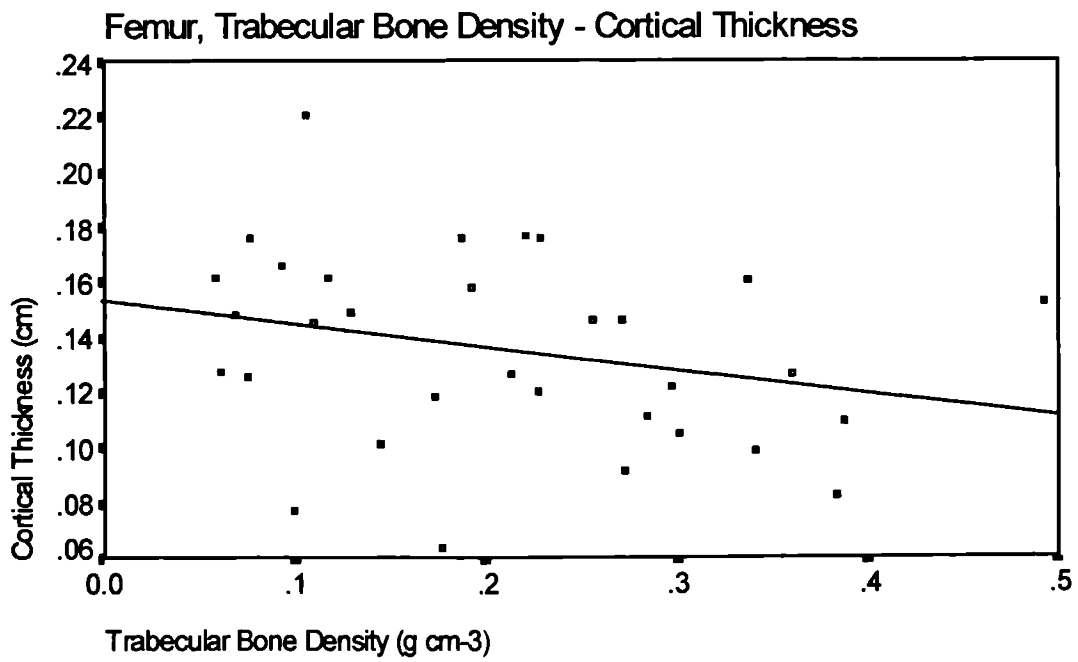


Figure 10.6.3 Femur trabecular bone base-line density data plotted against cortical thickness with least square regression line plotted. Correlation coefficient (Pearson) $r = -0.30$, p = 0.128. K-S (Lilliefors) p >0.2000.

The correlation between the femoral neck whole bone base-line density and the actual cortical thickness measurements was weakly positive but not significant. When the correlation between the trabecular bone base-line density and the cortical thickness was examined a weak negative correlation which was not significant was found.

10.7 Relationship between Cortical Index and Base-line Bone Density

10.7.1 Whole Bone Density

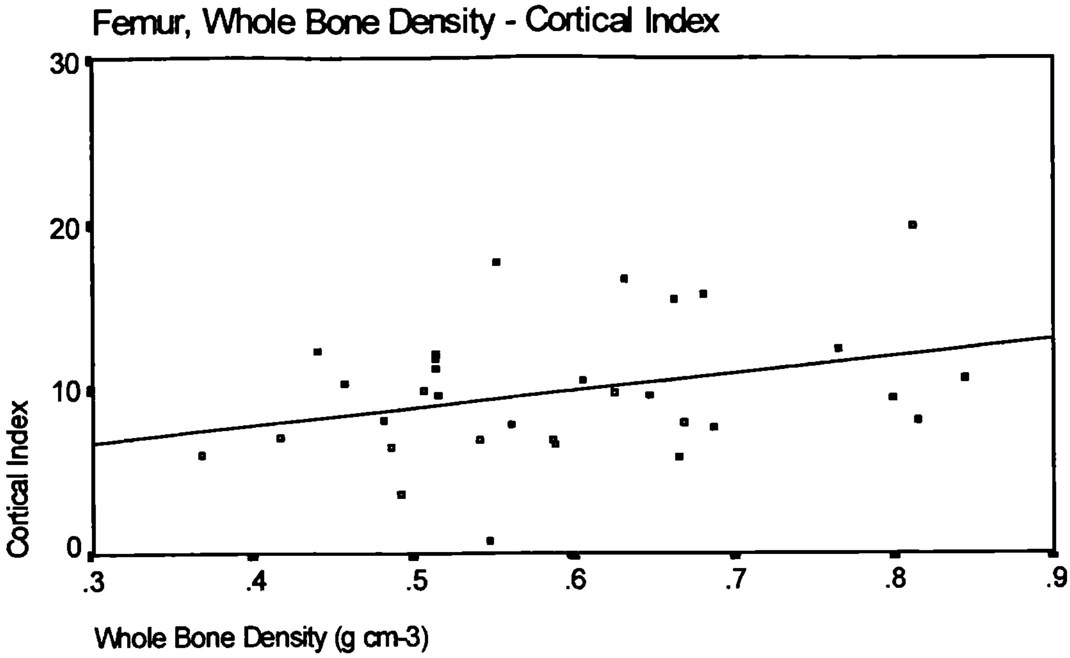


Figure 10.7.1 Femur whole bone base-line density data plotted against the cortical index with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.32$, $p = 0.760$. K-S (Lilliefors) $p > 0.2000$.

10.7.2 Trabecular Bone density

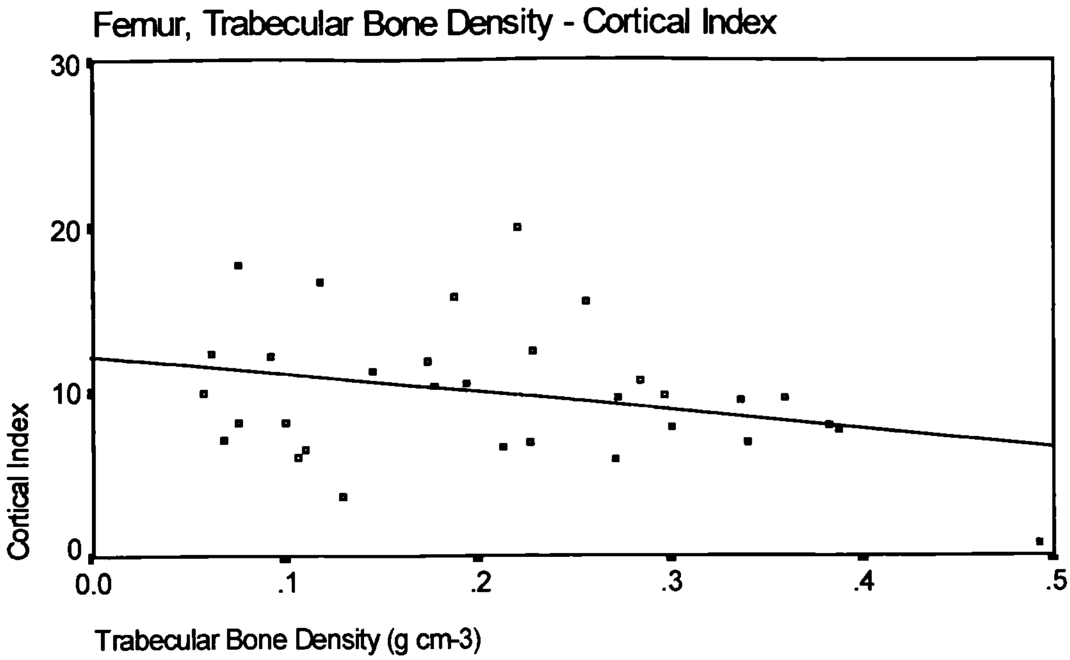


Figure 10.7.2 Femoral trabecular bone base-line density data plotted against cortical index with least square regression line plotted. Correlation coefficient (Pearson) $r = -0.03$, $p = 0.093$. K-S (Lilliefors) $p > 0.2000$.

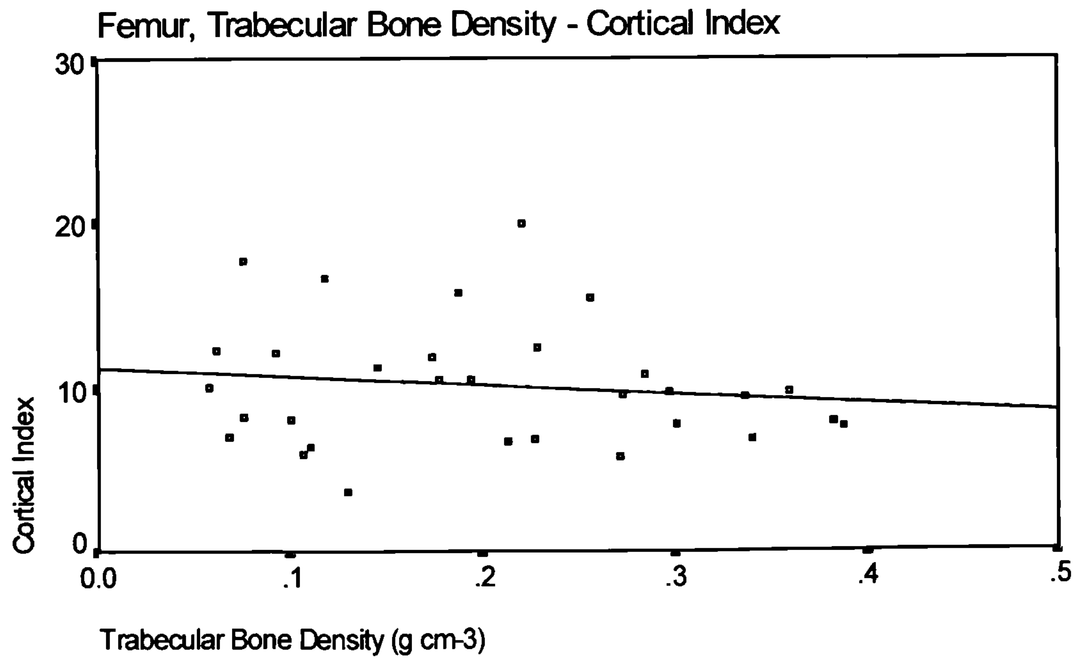


Figure 10.7.3 Femoral whole bone base-line density data cortical index plotted against with outliers removed. The least square regression line is plotted. Correlation coefficient (Pearson) $r = -0.16$, $p = 0.399$. K-S Lilliefors $p > 0.2000$.

There was a weak positive correlation between the femoral neck base-line density data and the cortical index. A weak negative correlation was found between the trabecular bone base -line density and the cortical index. When the outlier was removed from the plot the level of the correlation improved slightly. However, it was still very weak and negative. None of the correlations produced was significant.

10.8 The Relationship between Cortical Area and Base-line Bone Density

10.8.1 Whole Bone Density

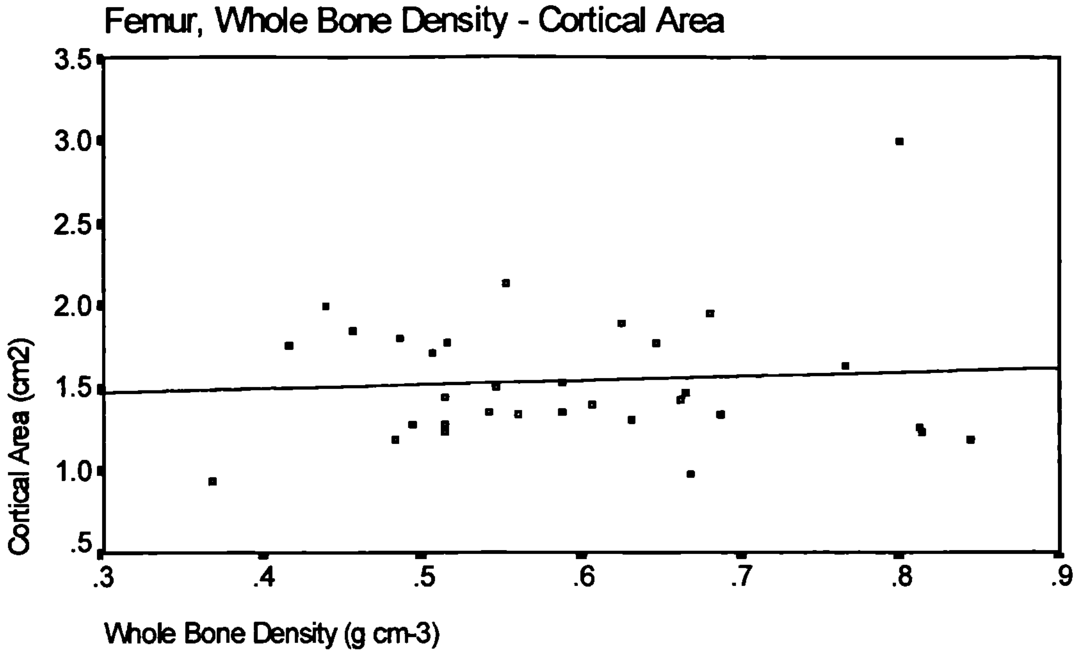


Figure 10.8.1 Femoral neck whole bone base-line density data plotted against cortical area with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.078$, $p = 0.672$. K-S Lilliefors $p > 0.2000$.

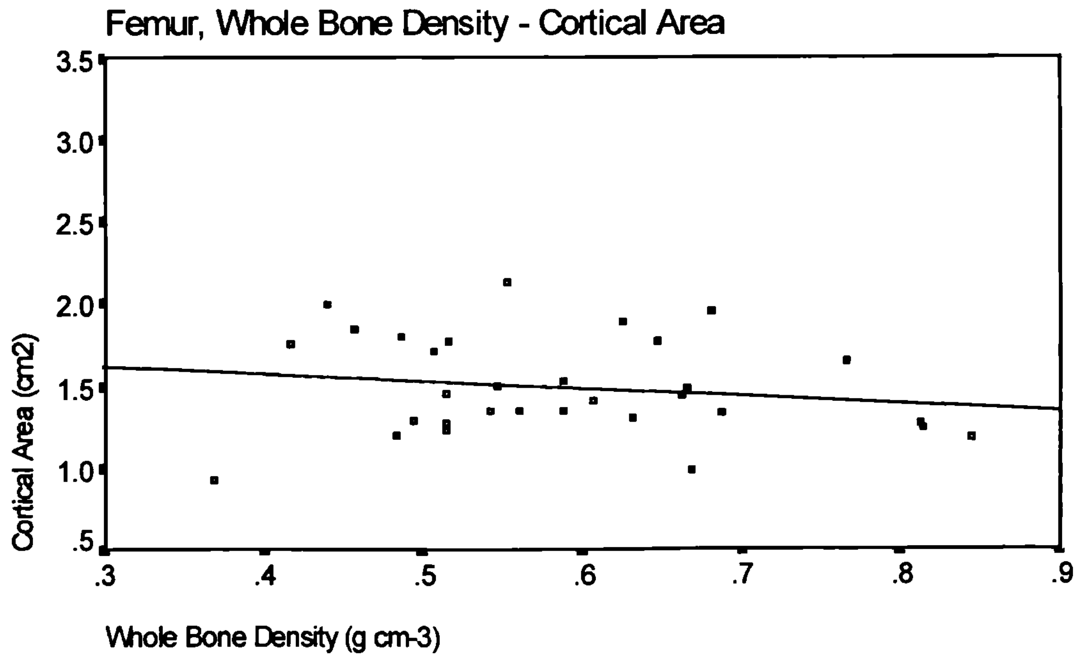


Figure 10.8.2 Femoral neck whole bone base-line density data plotted against cortical area with least square regression line plotted, with outlier removed. Correlation coefficient (Pearson) $r = -0.078$, $p = 0.337$. K-S Lilliefors $p > 0.2000$.

10.8.2 Trabecular Bone Density

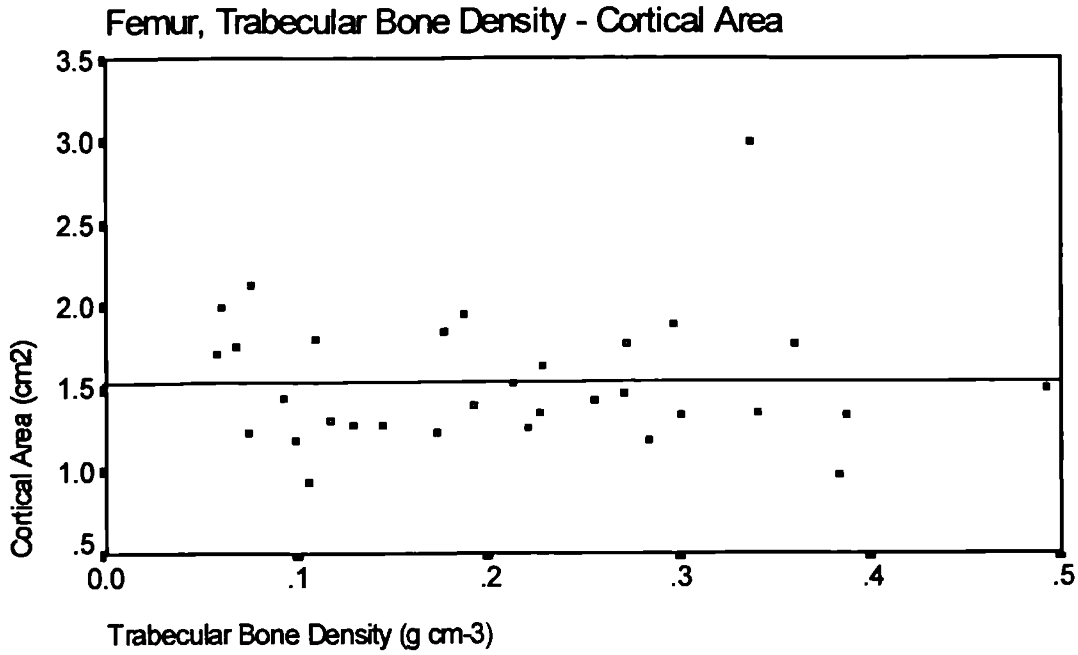


Figure 10.8.3 Femoral neck trabecular base-line density data plotted against cortical area with least square regression line plotted. Correlation coefficient (Pearson) $r = 0.04$, $p = 0.849$. K-S (Lilliefors) $p > 0.2000$.

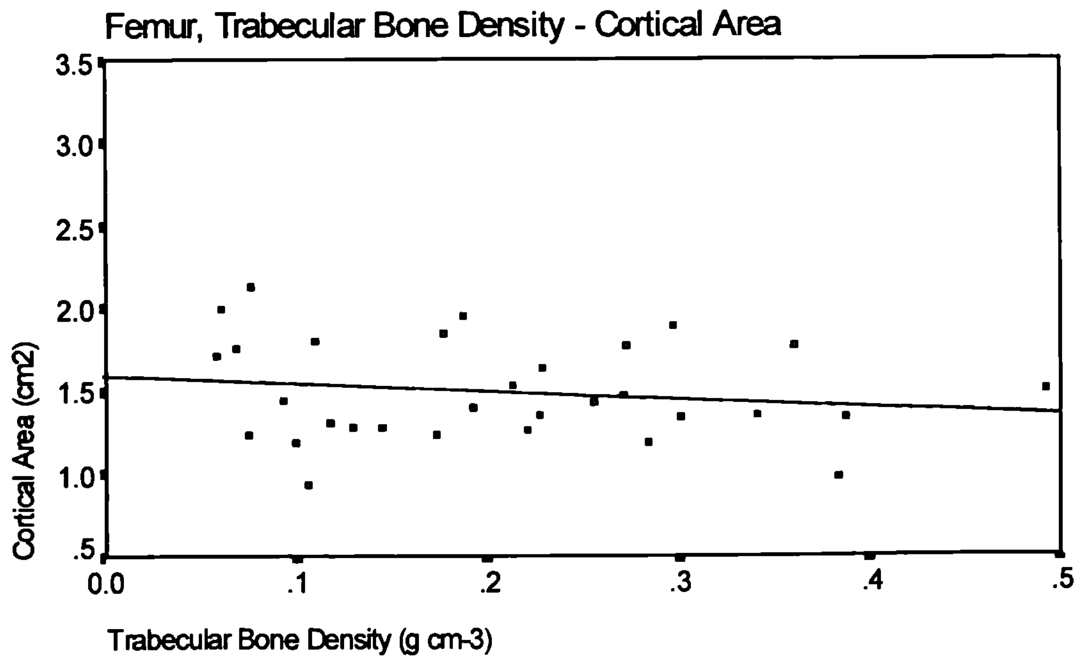


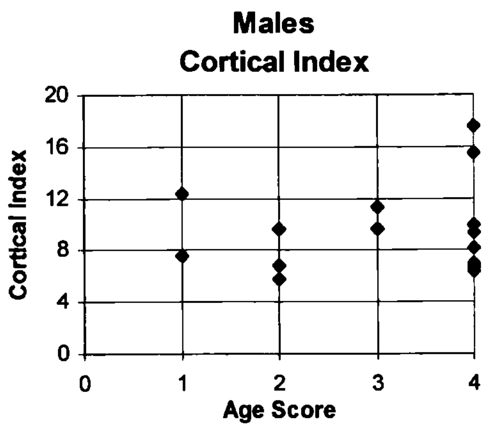
Figure 10.8.4 Femoral neck trabecular base-line density data plotted against cortical area with outlier removed. The least square regression line is plotted. Correlation coefficient (Pearson) $r = -0.17$, $p = 0.355$. K-S (Lilliefors) $p > 0.2000$.

There was a very weak correlation between both femoral neck whole bone and trabecular bone base-line density and the cortical area, and none of the correlations was significant. When the outlier was removed the correlations became negative, but were still very weak and not significant.

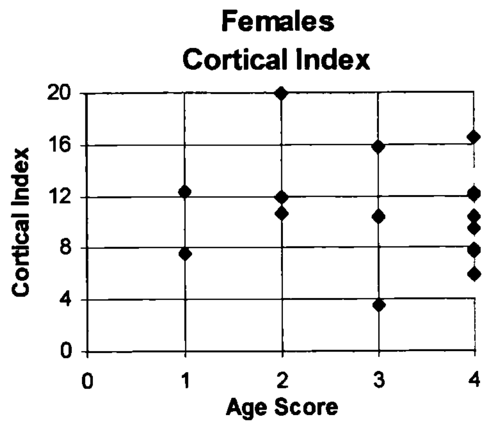
10.9 Relationship Between Age and Cortical Bone

The relationship between the estimated age at death of individuals from which the sample material was obtained and the data obtained from the cortical index, cortical thickness and cortical area are examined in this subsection. The skeletal element from which these measures of cortical bone were obtained is the femoral neck. In all cases sample numbers were not large enough for rigorous statistical analysis. The number of individuals in each age/sex category and data obtained for each technique are show in Table 10.2.1 to Table 10.4.1.

Figure 10.9.1 to Figure 10.9.3 show the estimated age at death plotted against the cortical index, cortical thickness and cortical area of the femoral neck.

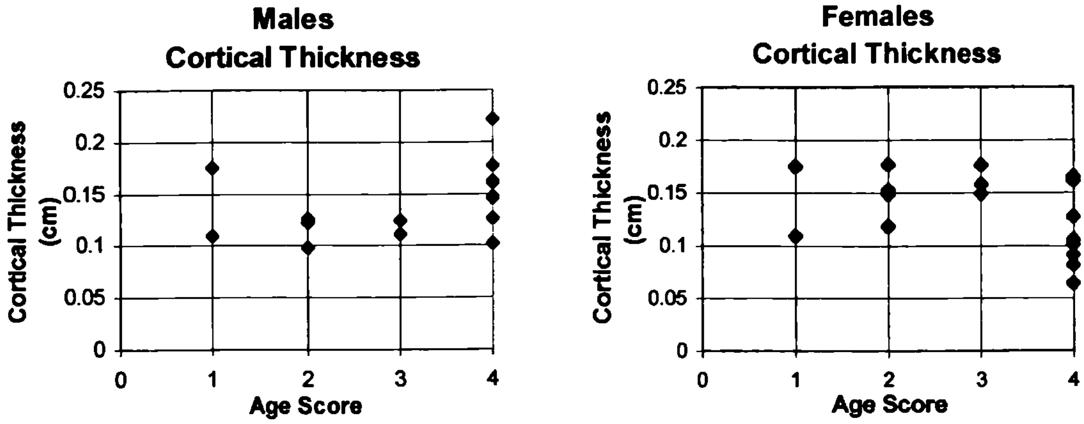


a)



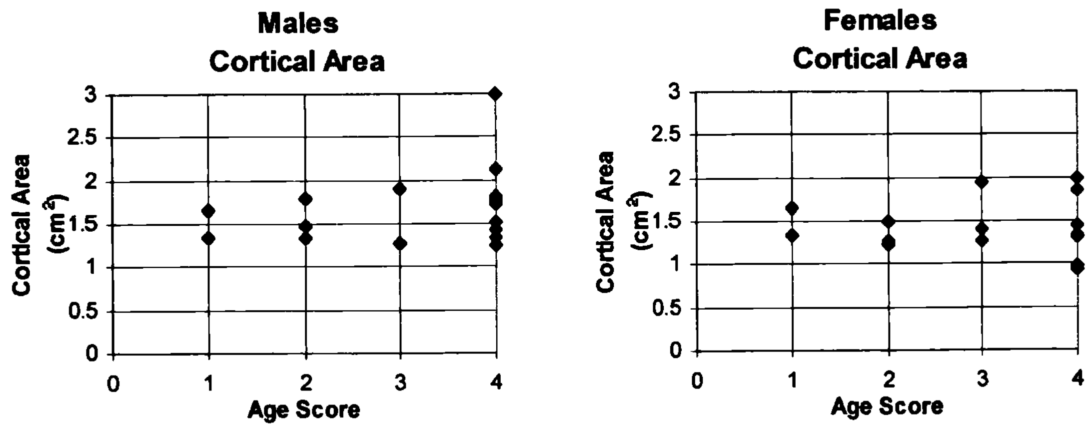
b)

Figure 10.9.1 Estimated age at death plotted against femoral neck cortical index results for a) males and b) females. Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.



a) **b)**

Figure 10.9.2 Estimated age at death plotted against femoral neck cortical thickness results for a) males and b) females. Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.



a) **b)**

Figure 10.9.3 Estimated age at death plotted against femoral neck cortical area results for a) males and b) females. Age score 1 = 15-25 years, age score 2 = 26-35 years, age score 3 = 36-45 years and age score 4 = 46+ years.

For all three measurements data was limited particularly for the age categories 15-25, 26-35 and 36-45. In each case no trend was seen in the data for females. However, in the male data there was a slight trend for measurements to increase in the oldest age category 46+, this was most pronounced in the data from the cortical thickness.

It should be noted that the pattern in these plots could be different if sample numbers were increased.

11. Summary of Results

In this section the results obtained in Sections 8, 9 and 10 are displayed in tables in a form which will allow comparisons to be easily made between the results of the different analyses. Table 11.1 details the results of the correlations between base-line density data and the cortical measures, non-invasive density techniques and slice optical densitometry, and structure as measured by the mean horizontal trabecular strut length. Table 11.2 shows the relationship between age/sex and base-line density data obtained from the vertebral bodies, and structure as measured by the mean horizontal trabecular strut length. The relationship of other techniques to the results of analysis of trabecular structure using the Singh index is also shown. Table 11.3 details the relationship between the different methods of measuring cortical bone.

Correlation between Base-line Density Data and all Other Investigative Techniques												
Technique	Femoral Neck (WB)		Femoral Neck (TB)		Vertebral Body (WB)		Vertebral Body (TB)		Radius		Iliac Crest	
	correlation	significance	correlation	significance	correlation	significance	correlation	significance	correlation	significance	correlation	significance
Optical Densitometry (CB)	0.70	p < 0.0001	0.79	p < 0.0001	0.82	sig < 0.0001	0.88	p < 0.0001	0.88	sig < 0.0001	0.77	p <0.0001
Optical Densitometry (BS)	0.62	p < 0.0001	0.78	p < 0.0001	0.72	p < 0.0001	0.84	p < 0.0001	0.80	p < 0.0001	0.71	p <0.0001
DEXA	0.52	p < 0.0001	0.69	p < 0.0001	0.65	p < 0.0001	0.80	p < 0.0001	0.77	p < 0.0001	0.70	p <0.0001
LAXS	0.75	p < 0.0001	0.84	p < 0.0001	0.82	p < 0.0001	0.92	p < 0.0001				
Singh Index	0.59	sig < 0.0001	0.54	sig < 0.001								
Stereometry					-0.40	p < 0.0001	-0.50	p < 0.0001				
Cortical Thickness	0.060	p = 0.743	-0.30	p = 0.128								
Cortical Area	0.078	p = 0.672	0.04	p = 0.849								
Cortical Index	0.32	p = 0.760	0.03	p = 0.093								

Table 11.1 Summary table of the correlation found between the base line density data and other techniques used in each bone element. WB indicates whole bone (cortex plus trabecular bone), TB indicates trabecular bone only. CB indicates that the complete bone was analysed and BS indicates that analysis was performed on the bone slice.

Relationship between Age/Sex and Investigative Techniques				
	Males		Females	
Measurement	correlation coefficient	significance	correlation coefficient	significance
Whole Bone Density (CS)	-0.076	p = 0.470	-0.34	p = 0.007
Whole Bone Density (SS)	-0.42	p = 0.024	-0.38	p = 0.019
Trabecular Bone Density (CS)	-0.069	p = 0.628	-0.38	p = 0.027
Trabecular Bone Density (SS)	-0.35	p = 0.160	-0.50	p = 0.011
Mean Trabecular Strut Length (SS)	0.89	p < 0.0001	0.76	p < 0.0001

Table 11.2 The relationship between age/sex and investigative techniques. CS refers to the complete sample set (all samples from Redcross Way and Farringdon Street). SS refers to the subsample (the randomly chosen sample from Redcross Way and Farringdon Street).

Correlation between Cortical Thickness Measurements						
	Cortical Thickness		Cortical Area		Cortical Index	
	correlation coefficient	significance	correlation coefficient	significance	correlation coefficient	significance
Cortical Thickness	*	*	0.15	p = 0.420		
Cortical Area					0.17	p = 0.348
Cortical Index	0.25	p = 0.175				

Table 11.3 The relationship between the different measures of cortical bone.

12. Discussion and Conclusions

12.1 Introduction

The aims of the work presented in this thesis were twofold. Firstly the historical and skeletal records were to be explored to discover whether osteoporosis was experienced by Londoners in the late 18th and early 19th centuries to a similar extent as it is today. Secondly, the methods available for its detection and measurement in archaeological skeletal material were to be evaluated, so that future studies could be carried out using the most instructive techniques.

A review paper by Agarwal and Grynpas (1996) concluded that "the pattern of bone loss and fragility seen in age-related and postmenopausal osteoporosis today is not evident in the past" (p. 429). The results of the present study clearly demonstrates that, at least for the material examined here, this is not the case. The patterns of the density changes with age in the fourth lumbar vertebral bodies shown in the archaeological material of the present study were similar to reported density changes throughout the skeleton for modern populations (Hui *et al.* 1987, Mazess 1982, Stevenson *et al.* 1989). Many previous studies have been ambiguous about their definition of osteoporosis, and most have also been ambiguous about their criteria for diagnosis of osteoporosis. It is apparent that even in clinical studies there are difficulties in diagnosis of osteoporosis from density data, due to the large and continuous range of densities found in all age categories (Chappard *et al.* 1988, Cummings 1987, Ross *et al.* 1990). Obtaining accurate results from archaeological bone has probably been complicated due to the techniques used and the problems of diagenesis. However, the results produced by many studies have indicated that age-related bone loss was taking place, and that this process appeared to be more rapid in females than males.

Agarwal and Grynpas (1996) suggested that diagenetic change may have produced erroneous results in some studies of archaeological bone material. They are correct in stating that researchers using archaeological bone material should be more aware of diagenesis as a potential source of error. In the present study diagenesis in bone samples was examined and sample material with significant amounts of calcium carbonate was excluded from the analysis. Many of the samples from Farringdon Street contained soil within the trabecular region of the bone slices, but these were cleaned. Following these precautions diagenetic changes should not have adversely influenced results obtained, from non-invasive investigative techniques and slice optical densitometry, in the present study. In the case of stereometric measurement only complete destruction of areas of the trabecular bone would adversely affect or prevent accurate analyses being carried out. The investigation into diagenetic changes within the sample material showed that care should be taken with all non-invasive investigative techniques applied to archaeological bone material. The changes observed were not found to be uniform across material from the sites of Redcross Way and Farringdon Street.

Agarwal and Grynpas (1996) stated that in past populations, "factors which compromise bone quality in osteoporosis today were not present, or somehow prevented" (p.429). There has never been a clear quantitative study of trabecular bone structure in archaeological bone material, and such work is extremely limited in modern bone. It is now widely known that trabecular bone quality plays an important role in the occurrence of osteoporosis-related fracture, and this fact is noted by Agarwal and Grynpas. Only one previous archaeological study has attempted to quantify trabecular bone changes (Kneissel *et al.* 1994), but the sample number was very small and trabecular number rather than length was analysed. Even so a high correlation was found between age of women and number of horizontal trabecular elements. A general qualitative description of trabecular changes observed in sectioned bones was given by Roberts and Wakely (1992), and Wakely *et al.* (1989). The patterns of age related loss appeared to be broadly similar to those described for the present population. However, the methods used in these papers did not allow quantification of changes in the trabecular bone. The results of the stereometric analysis in the present study indicate that patterns of bone loss in archaeological material from Redcross Way and Farringdon Street were very similar to those seen in the modern bone material reported by Jayasinghe (1991).

Agarwal and Grynpas (1996) suggested that there would have been fewer individuals who reached old age compared to the present day. This is correct in terms of the percentage of the population born, and therefore it is likely that fewer individuals would have developed age-related osteoporosis in comparison to the present day. However, analysis of death registers connected with London material in the present study demonstrated that there were still many individuals who reached an age at which they could be considered at risk from osteoporosis-related fracture.

"There is a rare, often absent, prevalence of osteoporotic fracture" (Agarwal and Grynpas 1996, p.423). There are a number of reports of osteoporosis-related fractures in archaeological material (Dequeker *et al.* 1997, Foldes *et al.* 1995, Frigo and Lang 1995, Mays 1996, Roberts and Wakely 1992), and although there can be difficulties in diagnosing these types of fractures in archaeological material, all seem to be plausible cases. It is probable that a greater awareness of the condition of osteoporosis over recent years has prompted people to look for fractures in archaeological material. Part of the reason why relatively few osteoporosis-related fractures have been noticed may be due to the fragility of the trabecular region of bone affected in this way. Micro-architectural structural changes associated with osteoporosis render bone more fragile, which is why fractures occur, and taphonomic processes may well have reduced the preservation potential of bones with reduced trabecular integrity with or without osteoporotic fractures. Bones such as vertebral bodies, which do not have a substantial cortex, may be particularly prone to taphonomic processes. It is clear from the review of historical literature of the period under study (A.D. 1700-1850) that age-related changes in bone structure, like those today associated with ageing and osteoporosis, were common. The type of bone loss described in some autopsy reports appears very similar to that seen in modern bone and accounts of fracture associated with low trauma in the elderly, appear similar to fracture associated with osteoporosis today. In these historical cases it cannot be definitely proved that the fractures described are due to osteoporosis, but all the evidence strongly suggests this. Although impossible to quantify from the material available, such fractures were common, and considered enough of a problem within the medical profession to engage in correspondence on the subject. It was even noticed that women were more susceptible than men. Fractures such as those of the femoral neck would have been very serious in the period under study. From the historical evidence it is apparent that even relatively simple fractures could cause long term disability if correct treatment was not given, and successful treatment of hip fractures would have been extremely difficult. It is evident that osteoporotic fractures would have caused considerable pain, disability and even death during the period under study. This is indicated by the case reports and also by "fracture of the thigh" being used as a specific cause of death in death registers. None of the treatments which are today available, such as physiotherapy and modern drugs, would have been available at this time.

Previous studies (Ericksen 1976, Lees *et al.* 1993) of age/sex related bone loss have focused on cultural aspects such as diet or levels of exercise in considering the way in which bone density and biological processes may have been different in the past. Modern research into osteoporosis shows that the number of factors associated with the onset and development of the condition are many and varied. Indeed age-related osteoporosis seems to be so multi-factorial in nature that it is hard to isolate any single factor. For example, in the populations under study, diet was undoubtedly of a lower quality than the average diet today but, on the other hand exercise levels would have been far greater. Caffeine consumption would have been lower because tea and coffee were expensive items, and there were no cheap soft drinks with high levels of caffeine as there are today. However, alcohol consumption was probably higher than that of the average person today. It can be seen from the accounts at the work house that ale was drunk in large quantities, because of the low quality of water available. Such conjecture about age-related bone loss in archaeological populations is fraught with difficulty, even in modern population studies it has proved impossible to weight the various contributory factors.

Data available from most archaeological studies of osteoporosis, including the present study, are complicated by the difficulties in accurately assigning an age at death to skeletal material. For adults, only broad age categories can be applied. Detailed subdivision into age categories for individuals over the age of fifty years is not possible in most archaeological material, and this was the case in the present study. This places severe limits on comparisons between modern populations and archaeological collections. The more detailed analyses of disease or other biological processes with age carried out on modern populations cannot be replicated in archaeology. In particular it is not possible to separate groups of women known to be pre- and post-menopausal. Many papers relating to clinical studies describe in detail the patterns of bone loss in older individuals, subjects are often split and analysed in specific older age categories. In many instances samples of women who are known to be pre-menopausal are included (Mazess *et al.* 1988, Riggs *et al.* 1982). Such a study is not possible with the data available in the present study. However, where feasible the relationship between results produced and estimated age at death was examined, although this was only possible for base-line bone density and structural analysis due to sample size. However, the broad age/sex relationships found in the present study have been compared with reported results from studies of bone loss in the modern population.

One feature of the present study was a comparison of several techniques across a range of skeletal elements. From an archaeological viewpoint it is important to examine a range of skeletal elements, because archaeological material is often fragmentary, restricting the choice of bones available for analysis. Also, even if well preserved, sectioning of a number of different skeletal elements from what may be museum or archival material may not be possible. Three main groups of material were used:

a)<u>Density</u>

The whole bone density (combined cortical and trabecular) was assessed by weight/volumetric analysis of the slices cut from the femoral neck, 4th lumbar vertebral body, distal radius and iliac crest. The density of trabecular bone on its own was additionally assessed in a similar way for femoral necks and vertebral bodies. The results of the weight/volumetric analysis are referred to as the base-line density. In addition, three non-invasive techniques were tested on the whole bone; optical densitometry, Dual Energy X-ray Absorptiometry (DEXA), and Low Angle X-ray Scattering (LAXS). Optical densitometry was also applied to the bone slices.

b)<u>Trabecular Structure</u>

The trabecular structural integrity were assessed qualitatively by visual and microscopic analysis of bone slices from the fourth lumbar vertebral body. A quantitative measure of the trabecular structural integrity of the fourth lumbar vertebral body was obtained from the measurement of horizontal trabecular elements. The trabecular structure of the Ward's triangle region, which includes the femoral neck, was assessed from radiographs using the Singh index.

c)<u>Cortical Bone Loss</u>

Cortical bone loss in the femoral neck was analysed by measuring the cortical thickness, cortical index, and cortical area. The cortical thickness was measured directly from the cut surface of the bone slices, the cortical index was obtained from radiographs, and the cortical area was obtained from photographs of the of the cut surface of the bone slices.

12.2 The Determination of Bone Density

Direct measurement of density (known as base-line density) was performed on whole bone slices and trabecular bone within the bone slices. The methodology used in calculation was simple and involved basic equipment, available to most university researchers. However, preparation of bone slices was very time consuming, and the calculation of the bone slice area, required for the volume determination, was slow without the aid of computer image analysis.

Clinically, it has been found that bone density varies widely in adults, with an extensive overlap in density between osteoporotic and normal individuals (Heaney 1989). It has also been noted that not all individuals with density low enough to be considered osteoporotic sustain an osteoporosis-related fracture (Arnold 1973). In the present study, the plots for whole bone density for the Redcross Way and Farringdon Street vertebral bodies highlighted these findings. There was a considerable overlap in density values between age/sex categories, with few statistically significant differences apart from the oldest and youngest categories. Even in young adults there was a wide range of densities. The range of densities recorded may have been exaggerated by inaccuracies in the ageing of archaeological bone, but it is clear that 'normal' bone density within each age/sex category varies considerably. This was not unexpected because the definition of osteopenia and osteoporosis through bone mineral density, or bone mineral content (BMC) is difficult (World Health Organisation, Geneva 1994), even in clinical studies. When the many problems associated with obtaining density/mass data for archaeological bone material are considered it is apparent that a definition of osteoporosis in archaeological bone material requires great care.

Clinically it has also been observed that both men and women lose bone with age, but that loss begins earlier and is more marked in women than men (Barlow 1994). These findings are confirmed by the results obtained from the 4th lumbar vertebral body in the present study of whole bone density in the vertebral body. Females showed a clearer age-related decline than males; even though the correlations were both small. The subsample (the sample on which stereometric analysis was performed) utilised an additional (older) age category and, in this group, the correlation between estimated age at death and density was stronger for both sexes. The division of samples of the age category 46+ into 46-55 years and 56+ probably caused the improvement of the correlation. In the subsample, the correlation in the males was slightly greater than that for females, which probably results from the males in this age category being on average much older than the females. The results produced by the present study are mirrored by clinical findings, which show peak bone density for the young adults (age category 26-35), and a decline from 36 years onwards (Spector 1991).

Clinical data document a decrease in bone mineral density with age in the spine, femur and radius as well as the vertebra (Mautalen *et al.* 1990). In the present study, the femoral neck, radius and iliac crest were analysed from Redcross Way only because of time constraints, and therefore sample numbers were not sufficient to perform rigorous statistical analysis. In most cases it was not possible to discern a clear relationship between estimated age at death and density, because sample numbers were small. However, there did appear to be a slight trend for bone density to decrease with age, for example in the female femoral neck whole bone density data and the radius data. In a few cases there was an indication that peak bone density fell from 36 years onwards, as in the males radius data. In the case of the femoral neck it was apparent that, unlike the vertebral body, the patterns produced by whole bone density and trabecular bone density were different. This may have been because the cortical bone at the femoral neck is far more substantial than that in the vertebral body and accounts for a significant proportion of the whole bone density. Such a result further indicates that the pattern of bone loss in cortical and trabecular bone is slightly different.

As there are no widely available non-invasive investigative techniques to measure the density of trabecular bone on its own the relationship between trabecular and whole bone base-line density (cortex and trabecular bone) was examined. The results suggest that the relationship between whole and trabecular bone density are stronger in the vertebral bodies (r = 0.88) than the femoral neck (r = 0.51), probably because cortical bone makes up a greater proportion of the overall density in the femoral neck than in the vertebral body.

Both clinical and archaeological studies of bone are often limited by the range of regions which can be sampled in order to determine the pattern of bone loss across the skeleton. Most archaeological bone forms part of a reference or teaching collection, and therefore it is often difficult to obtain permission to carry out invasive investigations. In studies of modern bone, biopsy samples are only available from the iliac crest, and non-invasive investigative techniques often involve patients receiving a radiation dose as well as being expensive to perform. For both types of study it is common that only one skeletal element will be available. Therefore knowledge of the relationship between different areas of the skeleton is very valuable. Work undertaken on autopsy material (Amling *et al.* 1996) and in clinical trials (Wright *et al.* 1990) showed that it is possible to draw conclusions about other skeletal areas through studying a single bone. Results from the present study indicate this is also the case in archaeological material, as correlations between skeletal areas were similar to those from studies of modern bone. Amling and co-workers (1996) found there was a correlation coefficient of r = 0.67 between bone mass in the spine and the femoral neck. The present study found a correlation of r = 0.65 between trabecular bone density at these two regions, and r = 0.70 for whole bone density. In a study which examined spinal bone mineral density and trabecular bone volume within the iliac crest a correlation coefficient of r = 0.60 was found (Wright *et al.* 1990). When bone mineral density in the vertebral body (spine) and iliac crest was examined in the present archaeological material, a correlation of 0.72 was produced. This is slightly higher than in the study by Wright, but in the present study both variables were bone mineral density, whereas Wright examined bone mineral density and trabecular bone volume. All bones examined in the present study (femoral neck, radius and iliac crest) produced a high, significant correlation with the vertebral body.

DEXA is one of the most commonly used clinical techniques for the determination of bone mineral density, and DEXA equipment is available in over ninety hospitals around Britain. However, it is heavily used clinically, and gaining access for archaeological studies is difficult, but the equipment is simple to operate. DEXA has been used in a number of previous studies of archaeological bone (for example, Bennike and Bohr 1990, Lees *et al.* 1993, Sambrook *et al.* 1988). Precision for normal DEXA readings on calibration phantoms is approximately 1%. The curve of precision obtained on the Redcross Way sample materials produced by Farquharson *et al.* (1997) showed that the accuracy of measurement for archaeological material decreased exponentially with decreasing density. For bones with very low density a result of zero was returned, which is clearly erroneous. These results made interpretation difficult. It is therefore probable that the standard DEXA software routines for clinical use are not suitable for archaeological samples of low bone density. This was most evident in the vertebral bodies and the radii. The reproducibility of DEXA on archaeological bone was evaluated by Raptis (1992) and found to be good, but no mention was made of the density of samples tested. The manufacturers (Lunar Corporation) do produce a software system, the "Small Animal" software, which can deal with bones of lower density, designed purely for research purposes and is not for clinical use. To date, the small animal software package has not been used in the study of archaeological bone, but it may be able to overcome difficulties associated with low bone density.

From the correlations obtained in the present study, it can be seen that DEXA could measure the bone mineral density of denser bones with reasonable accuracy. The correlation between base-line trabecular bone density and the DEXA data from the vertebral body was high, but correlation between vertebral body base-line whole bone density and DEXA data was not as good. This may be due to the fact that the scans were carried out through the end plates of the vertebral body, thereby including only tiny amounts of cortical bone in the scan. The best correlations were produced by the iliac crest, though it is not clear why this should be the case. The DEXA values of zero made interpretation of the relationship of age/sex with DEXA data difficult. However, there did appear to be a trend for density to decrease with age in some of the skeletal elements (for example the femoral neck in the males and vertebral bodies in the females).

Difficulties in determining bone loss with DEXA were discussed by Thompson (1991). It was estimated an individual would need to lose nearly 30% of bone mass before osteoporosis could be diagnosed using DEXA (Thompson 1991). This finding is not surprising considering the wide range of bone mineral density over which fractures are seen to occur. Using DEXA to diagnose osteoporosis in archaeological material will be less accurate because of loss of soft tissue (if clinical equipment is used) and diagenetic change. Particular care was taken in the present study to exclude samples which may have undergone some form of diagenetic change, but DEXA cannot be recommended for the sole determination of bone density in archaeological bone. Problems associated with diagenetic change have not always been addressed in other studies analysing archaeological material with DEXA (Lees *et al.* 1993, Sambrook *et al.* 1988).

LAXS is not widely available, and it was particularly fortunate that permission was granted to use the LAXS in the Medical Physics Department at UCL. In most cases it would not be possible for the researcher to carry out the analysis personally. Collaboration with a department with LAXS equipment would probably be necessary. This study is the first to apply the technique to archaeological bone. The LAXS configuration used was designed to measure only trabecular bone density, and the results obtained demonstrate that trabecular bone density can be measured accurately in archaeological material. The relationship between LAXS and base-line density was better for trabecular bone than whole bone density. LAXS produced the strongest correlations with base-line density of all the non-invasive techniques used for determining bone density, and gave the strongest pattern of age-related bone loss. However, only the vertebral body and femoral neck were examined using LAXS due to time constraints. There is no data with which to compare the results of the present study as initial studies have shown that the technique is not suitable for clinical use (Farquharson 1997).

LAXS can in fact be configured to examine any area of bone. For example, the whole bone including the cortex or an area of trabecular bone measuring square millimetres could be examined. This flexibility allows bones of any size to be examined. The limited investigations carried out in the present study also show that LAXS could be used to exclude archaeological material which had undergone diagenetic changes. Potentially, it could be a very important tool for studies of archaeological bone.

As in modern clinical studies (Cosman *et al.* 1991, Lindsay and Anderson 1978) optical densitometry was found to produce good results. In the present study the correlations produced using optical densitometry were similar, but slightly stronger, than those produced through DEXA analysis. However, unlike DEXA, the technology involved in optical densitometry is relatively unsophisticated and inexpensive, and is available in most universities. This technique also has little problem with bones of low density. In spite of these advantages, the present study is the first to apply optical densitometry to archaeological material. Strong, significant correlations were produced between base-line bone density data and optical densitometry data for all bone elements. Variation in the levels of correlation was probably due to variation in shape and thickness of the bones sampled. However, with archaeological material care must be taken as mineral inclusions within bones may be difficult to detect from radiographs, even when present in large quantities. Further work needs to be done in order to determine what the effect of such inclusions might be for a whole range of specimens. The effects of inclusions within a bone are relevant to a whole range of archaeological investigation involving radiographic analysis.

When applied to the bone slices, correlations between base-line trabecular bone density and optical densitometry of the bone slices were moderate to strong and all significant. As the slices were all of the same thickness, variation in the levels of correlation produced is probably due to differences in trabecular structure pattern. In all cases the whole bone optical densitometry produced stronger correlations with base-line density than the bone slice optical densitometry. This is probably an artefact related to the thickness of bone 'sampled' by the light source of the optical densitometer. With bone slices, a thickness of 5mm of bone was sampled whereas a much larger thickness of bone was sampled with radiographs of the complete bone. Bone slices therefore had a tendency, particularly for older individuals, to give 'anomalously' low readings of bone density where the light source sampled an area on the radiograph were no bone was detected by the X-ray machine. Optical density measurements on radiographs of the whole bone will not produce such anomalously low readings unless there is a hole that penetrates right through the bone. Thus, sectioning is not required to obtain reliable optical densitometry results, and the only advantage of bone slice optical densitometry, is that material inclusions, which may adversely affect results, can be detected.

12.3 Trabecular Bone Structure

The present study is the first to apply the Singh index to archaeological material. It might appear to have several advantages. The Singh index can be applied by any worker who can obtain radiographs of their sample material, and the scoring system is widely available, and the lack of soft tissue in archaeological bone material should make analysis of radiographs easier, although there is always the possibility of diagenetic inclusions affecting the interpretation of radiographs. However, in the present study the Singh index was found to be of limited value and elsewhere there are conflicting reports as to its usefulness. Hadberg and Nilson (1977) found a slight trend towards trabecular patterns defined by the Singh index in women who sustained a hip fracture, but they found that the Singh index could not be used as a predictive tool. A study by Kawashima and Uhthoff (1991) used cadaver material to test the Singh index against femoral dual photon absorptiometry (DPA) measurements and histomorphometry. They concluded that there was a good correlation between DPA measurements, histomorphometry results and the Singh index. The main problem appears to be the reproducibility of results (Dequeker *et al.* 1974, Kawashima and Uhtoff 1991, Khairi *et al.* 1976, Kovarik 1991, Singh *et al.* 1970). The reproducibility test undertaken in this study clearly demonstrated that, even when great care is taken, it can be very difficult to produce consistent scores for the same material. Of the techniques evaluated, it cannot rank highly as a method of choice for the study of archaeological bone.

The present study showed a moderate correlation between the Singh index and femoral neck whole bone base-line density data (r =0.59 $p < 0.001$), and a slightly weaker correlation with trabecular bone density (r = 0.54 $p < 0.001$). However, as the range of densities over which fracture may occur is very wide, these figures suggest that the index could not be used to identify osteoporosis. This study also found there to be a poor relationship between the Singh index and age.

Visual analysis of the vertebral body bone slices, however was able to determine a clear relationship between trabecular structure and age. This was consistent with smaller studies of modern material (Jayasinghe 1991) and archaeological bone (Roberts and Wakely 1992). Trabecular bone integrity decreased with age. Previous studies of trabecular bone loss in the modern population have noted that there is often a longer term preservation of the trabecular micro-architecture in men than women (Barlow 1994). The present study demonstrates that in the period under study women 'lost' more bone than men and that this loss started at an earlier age. In order to be able to clearly see if the pattern of trabecular bone in women is due to loss of bone, or if it is due to differences in trabecular structure between men and women a large sample of women in the age category 15-25 years would have to be examined. With age, the trabecular structure of men and women became more similar. A study by Jayasinghe and co-workers (1994) examined trabecular structure in fourth lumbar vertebral bodies from individuals who had been clinically diagnosed as having osteoporosis and non-osteoporotic older individuals. Clinical diagnosis is usually made on the basis of bone mineral density and/or the occurrence of fracture. Jayasinghe and co-workers noted that some samples from older individuals who had not been diagnosed as osteoporotic had the same drastically reduced bone structure as those that were. This demonstrates that direct observation of trabecular bone structure is a better means of assessing the state of bone and osteoporosis than density measurements. It was noted by Jayasinghe (1991) that in samples from individuals diagnosed as osteoporotic, vertical trabecular elements could be traced from one end plate to the other without difficulty. This was also found to be the case in a number of the older individuals included in the present study. A clear age/sex related pattern of trabecular bone loss such as that shown in the present study has been noted by other researchers working on modern bone material (Coupron *et al.* 1980, Mosekilde 1989).

Stereometric analysis was applied to a large enough sample to allow statistical analysis of the relationship between age/sex and trabecular bone structure. A clear age/sex related pattern was evident. Bone can clearly be seen to be lost with age, with loss starting earlier in women than men. In the older age categories men become more similar to women, although women always have longer trabecular strut lengths than men. When this is compared to the relationship determined for whole bone and trabecular vertebral body base-line density in the sub-group, it is apparent that the stereometric data produces a far clearer pattern of age/sex related bone loss. This is reflected by the correlation coefficients obtained for each type of analysis. Stereometric analysis gave a far stronger correlation with estimated age than that produced for the sub-sample for whole or trabecular base-line bone density.

From the data presented by Jayasinghe (1991) it is very hard to relate horizontal trabecular lengths given for the osteoporotic individuals to data obtained in the present study. The range of trabecular length measurements given for osteoporotic individuals was 0.65 - 2.67 mm for the males and 0.76 - 2.67 mm for the females. Of the sample in the present study 47% had trabecular lengths longer than 2.67 mm. Many of these also had trabecular lengths much shorter than 0.76mm. Overall the range observed was much greater than that reported in the study by Jayasinghe (1991). This may be due to the fact that a different section was cut from the vertebral body in this study, another factor may be that the sample in the study by Jayasinghe was very small (36 individuals). It is therefore not possible to be sure how many individuals could be considered osteoporotic from this data.

In the complete sample set of the present study (vertebral body), the females showed a low negative, but significant, correlation between density and estimated age. In the males the negative correlation was very weak and not significant. Similar to whole bone density, a stronger correlation was produced when the older age categories were subdivided, but in this case the negative correlation was stronger in the females than the males. This indicates that the females lost trabecular bone more rapidly and at an earlier age than males. Greater preservation of trabecular structures with age in males has also been found in modern bone material (Barlow

1994). Broadly the same pattern of loss was observed for both whole bone density and trabecular bone density in the vertebral bodies. This is probably due to the fact that cortical bone accounts for very little of the overall density of the vertebral body (Eastell *et al.* 1990).

In previous studies (Jayasinghe 1991, Vernon-Roberts 1973) the incidence of microcallus fractures was shown to increase with estimated age at death. Only three examples were found in the present study, but these were in older individuals. Free ending trabeculae and microcallus are indicative of a breakdown of the trabecular micro-architecture (Hahn *et al.* 1989, Heaney 1989). The numbers observed in the present study are too small to enable any firm conclusions to be drawn. However, the occurrence of free-ending trabeculae appeared to be broadly related to whole bone base-line density, though again the pattern is a little less clear in trabecular bone. The apparent greater incidence of free ending trabeculae may be due to the fact that they are easier to identify than microcallus. Microcallus were very difficult to observe even using microscopic examination and the fact that they were only observed in bone slices of very low density may be because they are far harder to see in bones densely occupied by trabeculae.

Stereometry has the advantage that it can be used on archaeological material irrespective of whether the bone has undergone any mineral exchange (e.g. carbonate addition, apatite loss, or coffin lead substitution). Compared to other methods through which similar information can be obtained, close range photogrammetry using stereo-pair photographs is comparatively simple and inexpensive using widely available equipment. For example, Chappard and co-workers (1988) undertook a study to examine the 3-D structure of trabecular bone. In order to do this a series of eight thin sections were made from a bone slice. This is clearly very time consuming and expensive when compared to preparation work required for stereometry. Stereometric analysis is not possible *in vivo*, but archaeological bone material provides an excellent opportunity to further this type of study.

Trabecular bone structure arrangement is important in the determination of osteoporosis related fracture structure (Beck *et al.* 1993, Jensen *et al.* 1990, Ross *et al.* 1990), and as in both archaeological and clinical investigations of bone loss invasive studies are not always possible the relationship between these two aspects of bone was examined. The complexity of the relationship between bone density and trabecular structure was clearly shown by the results of the present study. The correlation between trabecular structure (measured by mean trabecular length), and whole and trabecular bone base-line density was examined. Although significant, neither correlation was very strong, but as would be expected, the correlation for trabecular bone density was slightly stronger.

Differences between age-related changes can be observed on the plots produced for mean trabecular length plotted against age/sex and whole and trabecular bone base-line density in the sub-group plotted against age/sex. The bone density plots show a peak for both males and females in the age category 26-35 years. In comparison females have undergone considerable alteration of trabecular structure from the age category 15-25 years. This change is not apparent from the base-line density data. Overall, trabecular structure for males and females became more similar with age. This is not the case when data relating to bone density is examined. With base-line bone density, although variation with age is not uniform, the differences between males and females became more marked with age. The structural changes within trabecular bone are difficult to detect using density based techniques and this explains why investigative techniques using density determination cannot accurately predict fracture risk in elderly patients.

12.4 Cortical Bone Loss

Cortical bone from the femoral neck was assessed using cortical thickness, cortical index and cortical area. All of the techniques were technologically simple, although calculation of the cortical area is time consuming. However, this could be speeded up by using a computer image analysis system such as the one borrowed from the Wellcome laboratories in the present study. The correlation between these three measures was found to be extremely low and none was statistically significant. This is probably because each measures a slightly different aspect of cortical bone. The thickness of the cortex at the femoral neck was seen to be highly varied, and although it was determined from the mean of eight measurements, the figure obtained will not correspond directly with the cortical area. Similarly the cortical index estimates the percentage of the width of bone that is occupied by cortex and this is different to either the cortical area or thickness. Previous studies of archaeological bone have not compared data obtained from different measures of cortical bone.

There was a very low negative correlation between trabecular bone density and cortical thickness and a low positive correlation between cortical index and whole bone density in the femoral neck. Neither of these correlations was significant. There was a slight trend for decreasing cortical thickness and index in the females sampled, and this confirms results obtained from other studies of archaeological material in which the cortex was examined. Ericksen (1976) found higher levels of cortical bone loss in females than males. In a number of previous studies (Carlson *et al.* 1979, Thompson *et al.* 1981, Martin and Armelagos 1979) the males examined showed a gradual decrease of cortical thickness with age, but the loss in the females was greater. Mays (1996) found a decrease in the cortical index with age for the females but none for the males. Kerley (1961) observed in a study of archaeological bone material that gross cortical thickness was not consistently associated with age. This was also noted in the present study.

No clear age-related pattern was produced by the cortical index, cortical thickness or cortical area. With each method though there was a slight trend for the cortex to increase in size in males and to decrease in females. However, within the oldest age category there was a wide range of results for all three measures of cortex used. This is possibly due to the wide age range of sample material included in this age category. The overall pattern, although not statistically valid, was similar to that found in modern femoral samples by Feik and co-workers (1996). Feik and co-workers found that cortical thickness in males increased with age before decreasing at a much later age than the females. The females displayed a simpler pattern of cortical thickness change; thickness decreased slowly until the onset of menopause when there was a more marked decrease. It is possible the patterns reported by Feik and co-workers are reflected in the cortical thickness and cortical area data of the present study.

Cortical bone may in fact be more important than is indicated by the results obtained from the present study. Age/sex related alterations within the cortex due to osteoporosis are far more complex than a simple decrease in thickness. There may, for example, be changes in cortical porosity or overall shape with age (Karlsson *et al.* 1996). Cortical thinning, which can be detected through the techniques such as those used here, is the end point of a complex series of processes in which many factors play a role. Previous studies of archaeological bone have used measures of cortical bone as a convenient means through which to study bone loss (Mays 1996). It is clear that changes in cortical thickness with age are not simple relationships. There are probably changes in cross-sectional shape with age which complicate the pattern. Changes in the width and shape of long bones through remodelling processes with age in adulthood have been shown by a number of studies (Karlsson 1996, Nakamura *et al.* 1993). These studies have demonstrated that the circumference of the long bones increases with age. However, with remodelling imbalance levels of endocortical loss may cause the cortical thickness to decrease (Kanis 1994). The relationship between these two processes may provide an explanation for why cortical bone in males appears to increase before decreasing in later life.

12.5 Recommendations

This study of archaeological bone from the Redcross Way and Farringdon Street sites has shown that sectioning bones and analysis of the three dimensional micro-architecture of trabecular bone is the best approach to the study of bone loss and osteoporosis in past populations. If sectioning is not possible, then LAXS provides accurate measurements of bone mineral density, and bones can be screened to exclude samples which have undergone diagenetic changes. This technique can also be used to study trabecular bone density on its own, which has been shown to have a slightly stronger correlation with age/sex than whole bone density. However, LAXS equipment is not widely available. Whole bone optical densitometry is far more accessible and was found to provide reasonably high, significant correlations with base-line density data. Care must be taken with this technique in case diagenetic changes have occurred in the sample material. However, whichever technique is used to determine bone density, it must be remembered that the relationship between age-related bone loss and bone density is not straightforward, even in modern bone.

Of the four skeletal elements chosen in the present study (femoral neck , fourth lumbar vertebral body, distal radius and iliac crest), the fourth lumbar vertebral body was the most useful bone. It is easier to gain permission to section vertebrae than other bone elements, and transportation and storage are easier than for long bones such as the femur. In all the techniques used good results were obtained from the vertebral body. Also, as a result of previous work by Jayasinghe (1991), an approach to the study of trabecular bone structure within the vertebral bodies has already been defined. Such an approach has not yet been developed for use on other skeletal elements. Such a definition would allow patterns of trabecular bone loss across the skeleton to be better understood.

From the results obtained during the present study it was not possible to quantify the possible effect that diagenetic changes such as the inclusion of 'soils' within archaeological bone material might have on optical densitometry and other non-invasive investigative techniques applied to archaeological bone. Further work needs to be undertaken in order to asses potential error being introduced into studies of archaeological bone. The present study produced very promising results for the application of LAXS to investigations of archaeological bone. The sample analysed was however small and came from one archaeological site. A larger investigation of material is needed to see if similar results are produced, and to evaluate the full potential of the technique to identify diagenetic changes.

Although this study cannot recommend the use of clinical DEXA equipment, it would be interesting to see if more reliable results can be obtained through using research equipment such as the 'small animal software' produced by the Lunar corporation.

This study only included archaeological material from London populations dated 1700-1850. At this time there was massive population movement and many of the individuals included in the study would have come from all over Britain. This makes analysis of the results in terms of what is known about lifestyle factors particularly difficult. It would be useful to carry out a wider study involving material from different time periods and geographic locations in order to see if the pattern of age related bone loss observed in the population under study can be seen in other populations.

Future studies of archaeological bone should employ standardised techniques in order that direct comparisons can be made between studies. It is only through the analysis of larger samples that possible changes in the pattern of bone loss and osteoporosis can be identified. In order that such features can be accurately defined and a set of criteria through which osteoporosis can be diagnosed can be established studies involving modern bone of known age and medical history will have to be undertaken.

12.6 Conclusions

This study found that the best method by which bone loss leading to osteopenia (and possibly osteoporosis) could be detected in archaeological material was through analysis of trabecular structure in bone sections. This finding reflected recent research which has indicated that it is trabecular bone structure which has the most important role to play in bone loss, osteoporosis and the development of osteoporotic fractures.

However, it is not always possible to section archaeological bone. As in clinical studies, non-invasive techniques for the investigation of bone loss are needed. The relationship between bone density and micro-architectural change is not straightforward, but a moderately significant correlation was found in the present study. Trabecular bone density had a slightly stronger correlation with trabecular structure than whole bone density. Therefore methods such as LAXS which can investigate trabecular density alone are preferable to those which produce figures for whole bone density. This technique has the added advantage of giving information on diagenetic change. It overcomes the drawbacks involved with many of the other non-invasive investigative techniques but, LAXS equipment is not widely available. Whole bone optical densitometry is far more widely available, and showed high and significant correlations between data produced and base-line density data. Care must be taken when using this technique as diagenetic changes cannot be detected by optical densitometry. The relationship between cortical bone and age/sex was found to be complex, and to have a very weak relationship with density.

The diagnosis of osteopenia and osteoporosis on the basis of density techniques is problematic even in modern populations. The relationship between bone density and age/sex will always prove difficult, even if all the problems associated with archaeological bone, such as accurate age estimation and diagenetic change, can be overcome. However, the pattern of bone loss observed in this sample of London material dating to A.D. 1700-1850 is broadly the same as that reported for the modern population. The present study demonstrates that osteopenia and osteoporosis were present, and this finding is backed up by data from the medical literature from the period. From what is known about treatment of such fractures and their effect on the modern population it is certain that significant levels of pain, disability and death due to osteoporosis-related fractures were present in the population under study.

References

Acsadi G, Nemeskéri J (1970). *History of Human Life Span and Mortality.* Budapest: Akademiai Kiado.

Adran GM (1951). Bone destruction not demonstrable by radiography. *British Journal of Radiology* 24:107.

Agarwal SC, Grynpas MC (1996). Bone quantity and quality in Past Populations. *The Anatomical Record* 249:423-432.

Agren M, Karellas A, Leahy D, Marks S, Baron D (1991). Ultrasound attenuation of the calcaneus: A sensitive and specific discriminator of osteopenia in postmenopausal women. *Calcified Tissue Research* 48:240-4.

Aitken J (1771). *Essays on Several Important Subjects in Surgery: Chiefly on the Nature of the Fractures of the Long Bones of the Extremities.* London: E&C Dilly.

Alazraki N (1981). Bone imaging by radionuclide techniques. In (D Resnick, Niwayama G, Eds.), *Diagnosis of Bone and Joint Disorders, With Emphasis on Articular Abnormalities* Philadelphia: Saunders, pp. 639-78.

Amesbury J (1831). *Practical Remarks on the Nature and Treatment of Fractures of the Trunk and Extremities.* London: Longman.

Amling M, Herden S, Pösl M, Hahn M, Ritzel H, Delling G (1996). Hetrogeneity of the skeleton: Comarison of the trabecular microarchitecture of the spine, the iliac crest, the femur, and the calcaneus. *Journal of Bone and Mineral Research* 11:36-45.

Amundsen DW, Diers CJ (1970). The age of menopause in classical Greece and Rome. *Human Biology* 42:79-85.

Anderson JE (1962). *The Human Skeleton: A Manual for Archaeologists.* Ottawa: National Museum of Canada.

Anderson J, Osborn SB, Tomlinson RWS, Newton D, Salmon L, Rundo J, Smith JW (1964). Neutron activation analysis in man in *vivo*. A new technique in medical investigation. *Lancet* ii: 1201-5.

Arnett TR (1991). Physiology of the skeleton: In (Stevenson JC Ed.) *Osteoporosis.* Guildford: Reed Healthcare, pp. 10-14.

Arnold JS (1973). Amount and quality of trabecular bone in osteoporotic vertebral fractures. *Clinics in Endocrinology and Metabolism* 2:221-238.

Barlow DH (Ed.) (1994). *Report by the Advisory Group on Osteoporosis*. Whitehall London Department of Health.

Barnett E, Nordin BEC (1960). The radiological diagnosis of osteoporosis: A new approach. *Clinical Radiology* 11:166-74.

Bass WM (1987). *Human Osteology: A Laboratory and Field Manual.* (3rd edn.). Missouri Archaeological Society, Special Publication.

Beck TJ, Ruff CR, Bissessur K (1993). Age-related changes in female femoral neck geometry: Implications for bone strength. *Calcified Tissue International* 53 (Supl.1) : S41-S46.

Bell C (Sir) (1824). *Observations on Injuries of the Spine and of the Thigh Bone.* London: Tegg.

Bell LS (1990). Palaeopathology and diagenesis: An evaluation of structural changes using backscattered electron imaging. *Journal of Archaeological Science* 17:85-102.

Bell LS, Wong FS, Elliot JC, Boyde A, Jones SJ (1993). Post-mortem changes in buried human bone. *Journal of Anatomy* 183:196.

Bell NH, Sharpy J, Stevens J, Garza M, Gordon L, Edwards J (1991). Demonstration that bone mass is greater in black than in white children. *Journal of Bone Mineral Research* 6:719-723.

Bennike P, Bohr H (1990). Bone mineral content in the past and present. In (Christiansen C Overgaard K Eds.)*Third International Symposium on Osteoporosis*. Copenhagen: Osteopress pp. 89-91.

Bland JS, Brooks DH, Kent DJ, Fisher WH (1989). Evaluation of the clinical significance of appendicular skeletal assessment by radiographic photodensitometry. *Journal of Manipulative Physiological Therapy.* 12:113-9.

Boddington A, Garland AN, Janaway RC (1987). Flesh, bones dust and society. In: (Boddington A, Garland AN, Janaway RC, Eds.) *Death Decay & Reconstruction. Approaches to Archaeology & Forensic Science.* Manchester University Press, pp. 3-9.

Bohr H, Schaadt O (1983). Bone mineral content of femoral bone and the lumbar spine measured in women with fracture of the femoral neck by dual photon absorptiometry *Clinical Orthopaedics and Related Research* 179:240-245.

Boyce BF (1989). Bone biopsy and histomorphometry in metabolic bone disease. In (Stevenson JC Ed.) *New Techniques in Metabolic Bone Diseases*. London: Wright pp. 110-131.

Boyde A, Elliott JC, Jones SJ (1993). Stereology and histogram analysis of backscattered electron images: Age changes in bone. *Bone* 14:205-210.

Brock SL, Ruff CB (1988). Diachronic patterns of change in structural properties of the femur in the prehistoric American Southwest. *American Journal of Physical Anthropology* 75:113-127.

Brooks S, Suchey JM (1990). Skeletal age determination based on the OS Pubis: A comparison of the Acsadi-Nemeskeri & Suchy-Brooks methods. *Human Evolution* 5:227-238.

Brooks ST (1955). Skeletal age at death: The reliability of cranial and pubic age indicators. *American Journal of Physical Anthropology* 13:567-598.

Brothwell DR (1981). *Digging up Bones* (3rd edn.). USA: Cornell University Press:.

Buckland-Wright JC, Lynch JA, Rymer J, Fogelman I (1993). Fractal signature analysis of macroradiographs measures trabecular organization in lumbar vertebrae of Postmenopausal women. *Calcified Tissue International* 54:106-112.

Buikstra JE, DH, Ubelaker (Eds.) (1994). *Standards for Data Collection From Human Skeletal Remains. Proceedings of a Seminar at the Field Museum of Natural History.* Arkansas Archaeological Survey Research Seminar Series No. 44.

Burns TL (1992). Familiarity and partitioning the variability of femoral bone density in women of child bearing age. *Calcified Tissue International* 50:110-114.

Burr DB (1980). The relationship among physical, geometrical and mechanical properties of bone, with a note on the properties of non-human bone. *Yearbook of Physical Anthropology* 23:109-146.

Cann CE (1988). Quantitative CT for determination of bone mineral density: A review. *Radiology* 166:509-522.

Carbon RJ (1992). Exercise, amenorrhoea and the skeleton. *British Medical Bulletin* 48:546-60.

Carlson DS, Armelagos GJ, Van Gerven DP (1976). Patterns of age-related cortical bone loss (osteoporosis) within the femoral diaphysis. *Human Biology* 48:295-314.

Chalmers J, Ho KC (1970). Geographical variation in senile osteoporosis. *The Journal of Bone and Joint Surgery* 52B:667-675.

Chappard D, Alexandre C, Riffat G (1988). Spatial distribution of trabeculae in iliac bone from 145 osteoporotic females. *Acta Anatomy Basel* 132:137-42.

Chestnut CH (1991). Theoretical overview: Bone development, peak bone mass, bone loss and fracture risk. *American Journal of Medicine*, 91 (Suppl 5B):S2-S4.

Cheung RC-Y, Gray C, Boyde A, Jones SJ (1995). Effects of ethanol on bone cells *in vitro* resulting in increased resorption. *Bone* 16:143-147.

Cooper A (Sir) (1823a). Anatomical Investigations. *Lancet* pp. 62-67.

Cooper A (Sir) (1823b). Inspectio Cadavens. *Lancet* pp. 234.

Cooper A (Sir) (1824). *A Treatise on Dislocations and on Fractures of the Joints* (3rd edn.). London: Longman

Cooper C, Atkinson EJ, Wahner HW, O'Fallon WM, Riggs BL, Judd HL, Melton LJ (1992). Is caffeine consumption a risk factor for osteoporosis. *Journal of Bone Mineral Research.* 7 (4):465-71.

Cosman F, Herrington B, Himmelstein S, Lindsay R (1991). Radiographic absorptiometry: A simple method for determining bone mass. *Osteoporosis International* 2:34-38.

Coupron P, Lepine P, Arlot M, Lips P, Meunier P (1980). Mechanisms underlying the reduction with age of the mean wall thickness of trabecular basis structure unit (BSU) in human iliac bone. In (Jee WSS, and Parfitt AM, Eds.) *Bone Histomorphometry.* Paris: Armour Montagu pp.323-329.

Cuming R (1806). *The naval, military and private practitioners amanuesis, medicus et chirurgicus: Or a practical treatise on femurs and on amputation, gunshot wounds, trismus, scalds etc. and with new successful methods of treating mortification, of amputating at the shoulder joint, and of curing femoral fractures.* London: Mathews & Leigh.

Cummings SR, Kelsey JL, Newitt MC, O'Dowd KJ (1985). Epidemiology of osteoporotic fractures. *Epidemiology Review* 7:178-208.

Cummings SR (1987). Epidemiology of hip fractures. In (Christiansen C, Johansen JS, Riis BJ Eds.) *Osteoporosis 1987.* Virborg Denmark: Nohaven A/S pp. 40-44.

Cutler RG (1975). Evolution of human longevity and the genetic complexity governing ageing rate. *Proceedings of the National Academy of Sciences of the United States of America* 72:4664-4668.

Cutler RG (1978). Evolutionary biology of senescence. In (Behnke JA, Finch CE, Moment Eds.) *Ageing: Biology and Behaviour.* New York: Plenum Press pp.311-360.

Dargent P, Breart G (1993). Epidemiology and risk factors of osteoporosis. *Current Opinion in Rheumatology* 5:339-345.

Delmas PD (1993). Bone mass measurement: How, where, when and why? *International Journal of Fertility and Menopausal Studies* 38(S2):70-76.

Dempster DW, Lindsay R (1993). Pathogenesis of osteoporosis. *The Lancet* 341: 797-801.

Dequeker J, Gautama K, Roh YS (1974). Femoral trabecular patterns in asymptomatic spinal osteoporosis and femoral fracture. *Clinical Radiology* 25:243-246.

Dequeker J, Ortner DJ, Stix AI, Cheng X, Brys P, Boonen S (1997). Hip fracture and osteoporosis in a XIIth dynasty female skeleton from Lisht, Upper Egypt. *Journal of Bone and Mineral Research* 12:881-888.

Diamond T, Stiel G, Posen S (1989). Osteoporosis in haemochromatosis: Iron excess gonadal deficiency or other factors? *Annals of Iternal Medicine* 110:430-436.

Douglas B, Hanson JE, Buikstra (1987). Histomorphological alterations in buried human bone from the Illinois Valley: Implications for paleodietary research. *Journal of Archaeological Science* 14:549-563.

Eastell R, Vieira NA, Yergey AL, Wahner HW, Silverstein MN, Kurmar R, Riggs BL (1992). Pernicious anaemia as a risk factor for osteoporosis. *Clininical Science Colchester* 82 (6): 681-5.

Efremov IA (1940). Taphonomy: A new branch of palaeontology. *Pan-American Geologist* 74:81-93.

Ericksen MF (1976). Cortical bone loss with age in three native American populations. *American Journal of Physical Anthropology* 45:443-452.

Eriksen EF, Mosekilde L, Melsen F (1985). Trabecular bone resorption depth decreases with age: Differences between normal males and females. *Bone* 6:141-6.

Ernst E (1992). Smoking is a risk factor for spinal disease. Hypothesis of the pathomechanism. *Weiner Klinische Wochenschrift* 104:626-30.

Ernst E (1993). Smoking, a cause of back trouble? *British Journal of Rheumatology* 32:239-42.

Faccini JM, Exton-Smith AN, Boyde A (1976). Disorders of bone and fracture of the femoral neck. *The Lancet* 1(7969), 1089-1092.

Farquharson MJ PhD (1996). *Characterisation of Bone Tissue Using Coherently Scattered X-ray Photons.* PhD thesis, University of London.

Farquharson MJ, Brickley M, Speller RD (1997). Measuring bone mineral density in archaeological bone using energy dispersive low angle X-ray scattering techniques. *Journal of Archaeological Science* 24:765-772.

Farquharson MJ, Brickley M (1997). Determination of mineral composition of archaeological bone using energy-dipersive low-angle X-ray scattering. *International Journal of Osteoarchaeology* 7:95-99.

Feik SA, Thomas CDL, Clement JC (1996). Age trends in remodelling of the femoral midshaft differ between the sexes. *Journal of Orthopaedic Research* 14:590-597.

Fenton-Lewis (1981). Fracture of neck of the femur: Changing incidence. *British Medical Journal* 283:1217-1219.

Finlay RAP, Shearer B (1986). Population Growth and Suburban Expansion. In (AL Beier R Finlay Eds.) *London 1500-1700: The Making of the Metropolis*. London: Longman, pp. 37-59.

Finsen V, Anda S (1988). Accuracy of visually estimated bone mineralization in routine radiographs of the lower extremity. *Skeletal Radiology* 1951:24-107.

Fogelman I (1996). The effects of oestrogen deficiency on the skeleton and its prevention. *British Journal of Obstetric Gynaecology* 103 (Supl. 14):S5-S9.

Foldes AJ, Moscovici A, Popovtzer MM, Mogle P, Urman D, Zias J (1995). Extreme osteoporosis in a sixth century skeleton from the Negev desert. *International Journal of Osteoarchaeology* 5:157-162.

Foldes AJ, Popovtzer MM (1996). Osteoporosis 4000 years ago. *New England Journal of Medicine* 334:735.

Frigo P, Lang C (1995). Osteoporosis in a woman of the Early Bronze Age. *New England Journal of Medicine* 333:1468.

Gallagher JC (1990). The pathogenesis of osteoporosis. *Bone Mineral* 9:215-227.

Garland AN (1987). A histological study of bone decomposition. In (Boddington A, Garland A, Janaway R, Eds.). *Death Decay & Reconstruction: Approaches to Archaeology & Forensic Science.* Manchester University Press, pp.109-126.

Gennari C, Civitelli R (1986). Glucocorticoid-induced osteoporosis. *Clinical Rheumatology* 12:637-654.

George M (1925). *London Life in the Eighteenth Century.* London: Kegan Paul, Trench, Trubner.

Geraets GM, Van Der Stelt PF, Netelenbos CJ, Elders PJM (1990). A new method for automatic recognition of the radiographic trabecular pattern. *Journal of Bone and Mineral Research* 5:227-233.

Gilbert BM, Mckern TW (1973). A method for ageing the female Os Pubis. *American Journal of Physical Anthropology* 38:147-156.

Gluer CC, Vahlensieck M, Faulkner KG, Engelke K, Black D, Genant HK (1992). Site-matched calcaneal measurements of broad-band ultrasound attenuation and single x-ray absorptiometry: do they measure different skeletal properties? *Journal of Bone Mineral Research* 7:1071-9.

González-Reimers E, Arnay-de-la-Rosa M (1992). Ancient skeletal remains of the Canary Islands: Bone histology and chemical analysis. *Anthropologie Anzeiger* 50:201-215.

Goulding A (1981). Fasting urinary sodium/creatinine in relation to calcium/creatinine and hydroxyproline/creatinine in a general population of women. *New Zealand Medical Journal* 93:294-297.

Gray RH (1976). The menopause-Epidemiological and demographic considerations. In (Beard RJ Ed.). *The Menopause: A Guide to current Research and Practice.* Baltimore: University Park Press pp.25-40.

Grote HJ, Amling M, Vogel M, Posl M, Delling G (1995). Intervertebral variation in trabecular microarchitecture throughout the normal spine in relation to age. *Bone* 16:301-308.

Hackett CJ (1981). Microscopical focal destruction (tunnels) in exhumed human bones. *Medicine Science and the Law* 21:243-265.

Hagberg L, Nilsson BE (1977). Can fracture of the femoral neck be predicted? *Geriatrics* 32:55-61.

Hahn M, Vogel M, Pompesius Kempa M, Delling G (1989). *Kombinierte zwei-und dreidimensionale analyse der wirbelsaule als grundlage fur das verstandis endokriner knochenmassenverlust- syndrome.* Quintessenz Verlags Gmbh Berlin.

Hanson DB, Buikstra JE (1987). Histomorphological alteration in buried human bone from the lower Illinois valley: Implications for research. *Journal of Archaeological Science* 14:549-563.

Hazon G, Leicher I, Loewinger E, Weinreb A, Robin GC (1977). The early detection of osteoporosis by Compton-ray spectroscopy. *Physics in Medicine and Biology* 22:1073-84.

Heaney RP, Recker RR, Saville PD (1978). Menopausal changes in bone remodelling. *Journal of Laboratory and Clinical Medicine* 92:964-70.

Heaney RP, Recker RR (1982). Effects of nitrogen phosphorous and caffeine on calcium balance in women. *Journal of Laboratory and Clinical Medicine* 99:46-55.

Heaney RP (1989). Osteoporotic fracture space: An hypothesis. *Bone Mineral* 6:1-13.

Heaney RP, Yates AJ, Santora AC (II) (1987). Bisphosphonate effects and the bone remodelling transient. *Journal of Bone and Mineral Research* 12:1143-1151.

Henderson J (1987). Factors determining the state of preservation of human remains. In (Boddington A, Garland AN, Janaway RC, Eds.). *Death Decay and Reconstruction. Approaches to Archaeology and Forensic Science.* Manchester: Manchester University Press pp.43-54.

Horsman A, Leach AE (1974). Estimation of the cross-sectional area of the ulna and radius. *American Journal of Physical Anthropology* 40:173-186.

Howell PGT, Boyde A, Ross HF (1986). A three axis stereocomparator for scanning electron microscopic photogrammetry - RS3. *Scanning* 8:182-186.

Hui SL, Slemenda CW, Johnston CC, Appeldorn CR (1987). Effects of age and menopause on vertebral bone density. *Bone Mineral.* 2:141:6.

Inoue T, Kushida K, Kobayashi G, Machida A, Yamazaki K, Sugiyama E, Watanabe H (1993). Exercise therapy for osteoporosis. *Osteoporosis International* (Supl. 1):S166-S8.

Iscan MY, Loth SR, Wright RK (1984). Age estimation from the rib by phase analysis: White Males. *Journal of Forensic Sciences* 29:1094-1104.

Iscan MY, Loth SR, Wright RK (1985). Age estimation from the rib by phase analysis: White females. *Journal of Forensic Sciences* 30:853-863.

Jayasinghe JAP (1991). *A study of change in human trabecular bone structure with age and during osteoporosis.* Ph.D. Thesis UCL London.

Jayasinghe JAP, Jones SJ, Boyde A (1994). Three-dimensional photographic study of cancellous bone in human fourth lumbar vertebral bodies. *Anatomy & Embryology* 189:259-274.

Jensen KS, Mosekilde L, Mosekilde L (1990). A model of vertebral trabecular bone architecture and its mechanical properties. *Bone* 11:411-415.

Jones CD, Laval-Jeantet AM, Genant HK (1987). Importance of measurement of spogious vertebral bone mineral density in the assessment of osteoporosis. *Bone* 8:201-6.

Kanis JA (1991). Calcium requirements for optimal skeletal health in women. *Calcified Tissue International,* 49:S33-41.

Kanis JA, Pitt FA (1992). Epidemiology of Osteoporosis. *Bone* 13:S7-15.

Kanis JA (1994). *Osteoporosis.* Oxford: Blackwell Scientific Publications.

Karlsson KM, Sernbo I, Obrant KJ, Redlund-Johnell I, Johnell (1996). Femoral neck geometry and radiographic signs of osteoporosis as predictors of hip fracture. *Bone* 18:327-330.

Kawashima T, Uhthoff HK, (1991). Pattern of bone loss of the proximal femur: A radiologic, densitometric and histomorphometric study. *Journal of Orthopaedic Research* 9:634-640.

Keen JA (1950). A study of the differences between male and female skulls. *American Journal of Physical Anthropology* 8:65-79.

Kelly PJ, Eisman JA, Stuart MC, Pockock NA, Sambrook PN, Gwinn TH (1990). Somatomedin-C, physical fitness and bone density. *Journal Clinics in Endocrinology and Metabolism* 70:718-723.

Kerley ER (1961). The microscopic determination of age in human bone. Doctoral dissertation, University of Michigan, Ann Arbor.

Khairi MRA, Cronin JH, Robb JA, Smith DM Yu PL, Johnston CC (1976). Femoral trabecular-pattern index and bone mineral content measurement by photon absortiometry in senile osteoporosis. *Journal of Bone and Joint Surgery (America)* 58A:221-226.

Kingsmill V (1996). *Bone Structure and Turnover in the Adult Human Mandible.* PhD thesis, University of London.

Kleerekoper M, Feldkamp LA, Goldstein SA, Flynn MJ, Parfitt AM (1987). Cancellous bone architecture and bone strength. In (Christiansen C, Johansen JS, Riis BJ, Eds.). *Osteoporosis 1987.* Virborg Denmark: Norhaven A/S, pp. 294-300.

Kleerekoper M, Avioli LV (1990). Evaluation and treatment of postmenopauasal osteoporosis In (Favus MJ, Ed.). *Primer on the Metabolic Bone Diseases and Disorders of Mineral Metabolism.* American Society for Bone and Mineral Research, California, pp. 151-154.

Kneissel M, Boyde A, Hahn M, Treschler-Nicola M, Kalchhauser G, Plenk H. jr. (1994). Age- and sex-dependent cancellous bone changes in a 4000y BP population. *Bone* 15:539-545.

Kovarik J, Kuster W, Seidl G, Linkesch W, Dorda W, Willvonseder R, Kotscher E (1991). Clinical relevance of radiologic examination of the skeleton and bone density measurements in osteoporosis of old age. *Skeletal Radiology* 7:37-41.

Kranendonk DH, Jurist JM, Gunn Lee H (1972). Femoral trabecular patterns and bone mineral content *Journal of Bone and Joint Surgery (America)* 54A:1472-1478.

Kruse HIP, Kuhlencordt F (1983) Studies in primary osteoporosis. In (St John Dixon A, Russell RGG, Stamp TCB Eds.). *Osteoporosis, A Multi-Disciplinary Problem* London: Academic Press pp.149-152.

Laitinen K, Lamberg-Allardt C, Tunninen R (1991). Effects of three weeks moderate alcohol intake on bone and mineral metabolism in men. *Bone & Mineral* 13:139-152.

Lamberg-Allardt C (1991). Is there a role for vitamin D in osteoporosis. *Calcified Tissue International* 49:46-9.

Lammbert JB, Simpson SV, Szpunar CB, Buikstra JE (1985). Bone diagenesis & dietary analysis. *Journal of Human Evolution* 14:477-482.

Landers J (1993). *Death and the Metropolis. Studies in the Demographic History of London 1670-1830.* Cambridge: Cambridge University Press.

Lapedes DN (Ed.) (1978). *Mc Graw-Hill Encyclopaedia of the Geological Sciences.* Mc Graw-Hill Inc: New York pp.153-155.

Lees B, Molleson T, Arnett TR, Stevenson JC (1993). Differences in proximal femur bone density over two centuries. *The Lancet* 341:673-675.

Lewinnek G, Kesley J, White A, Kreiger N (1980). The significance and comparative analysis of the epidemiology of hip fractures. *Clinical Orthopaedics* 152:35-43.

Lindsay R, Anderson JB (1978). Radiologogical determination of changes in bone mineral content. *Radiography* 44:21-6.

Liston *N.L.H. Surgical Cases Female Wards Mr Liston's Female Cases.* November 1834 - November 1836. UCH/MR/1/1-63.

Lohman T (1992). Exercise Training and body composition in childhood. *Canadian Journal of Sports Science* 17:284-287.

Lovejoy CO, Meindl RS, Pryzbeck TR, Mensforth RP (1985). Chronological metamorphosis of the auricular surface of the ilium: A new method for the determination of adult skeletal age at death. *American Journal of Physical Anthropology* 68:15-28.

Lukert BP (1994). Vertebral compression fractures: How to manage pain, avoid disability. *Geriatrics* 49:22-6.

MacDonald BR, Gowen M (1993). Cell biology of bone, 421-439. In (Reid DM Ed.) *Baillieres Clinical Rheumatology* 7 (3).

Marchiafavia V, Bonucci L, Ascenzi A (1974). Fungal osteoclasia: A model of dead bone resorption. *Calcified Tissue Research* 14:195-210.

Martin DL, Armelagos GJ (1979). Morphometrics of compact bone: An example from Sudanese Nubia. *American Journal of Physical Anthropology* 51:571-578.

Matkovic V, Kostial K, Simonovic I, Buzina R, Brodarec A, Nordin BEC (1979). Bone status and fracture rates in two regions of Yugoslavia. *American Journal of Clinical Nutrition* 32:540-549.

Matkovic A, Fontana D, Tominac C, Goel P, Chestnut CH 3rd, (1990). Factors that influence peak bone mass formation: A study of calcium balance and the inheritance of bone mass in adolescent females. *American Journal of Clinical Nutrition* 52:878-88.

Mautalen C, Vega E, Ghiringhelli G, Fromm G (1990). Bone diminution of osteoporotic females at different skeletal sites. *Calcified Tissue International* 46:217-221.

Mays SA (1996). Age-dependent cortical bone loss in a Medieval population. *International Journal of Osteoarchaeology* 6:144-154.

Mazess RB (1982). On ageing bone loss. *Clinical Orthopaedics* 165:239-52.

Mazess RB, Wheldon GD (1983). Immobilisation and bone. *Calcified Tissue International* 35:265-7.

Mazess RB, Barden H, Ettinger M, Schultz E (1988). Bone density of the radius, spine, and proximal femur in osteoporosis. *Journal of Bone and Mineral Research* 3:13-18.

McKern TW, Stewart TD (1957). *Skeletal age changes in young American males.* U.S. Army Quartermaster Research and Development Command, Technical Report EP-45. Natick, Mass.

McKinlay SM, Jeferys M, Thompson B (1972). An investigation of the age at menopause. *Journal of Biosocial Sciences* 4:161-173.

McInnes EM (1963). *St. Thomas' Hospital.* London: G. Allen & Unwin.

McMinn RMH, Hutchins RT (1988). *A Colour Atlas of Human Anatomy.* Wolfe Medical Publications, London

Meindl RS, Lovejoy CO (1985). Ectocranial suture closure: A revised method for the determination of skeletal age at death. *American Journal of Physical Anthropology* 68:57-66.

Mellish RWE, Ferguson-Pell MW, Cochran GVB, Lindsay R, Dempster DW (1991). A new manual method for assessing two-dimensional cancellous bone structure: Comparison between iliac crest and lumbar vertebra. *Journal of Bone and Mineral Research* 6:689-696.

Melton JL, III, Chrischilles EA, Cooper C, Lane AW, Riggs LB (1992). Perspective, how many women have osteoporosis. *Journal of Bone & Mineral Research* 7:1005-1010.

Melton JL, Bryant SC, Wahner HW, O'Fallon WM, Malkasian GD, Judd HL, Riggs BL (1993). Influence of breastfeeding and other reproductive factors on bone mass in later life. *Osteoporosis International* 3:76-83.

Miles AWE (1963). Dentition in the assessment of individual age in skeletal material. *Journal of Dental Research* 42:255-263.

Miles A (1992). *Interim Report on St. Saviours Burial Ground.* Museum of London Archaeology Service.

Miles A (1993). *St Saviours Burial Ground, Redcross Way London Borough of Southwark. An Archaeological Excavation.* London: Museum of London Archaeology Service.

Miller CW (1978). Survival and ambulation following hip fracture. *Journal of Bone and Joint Surgery* 60A:930-934.

Molleson T, Cox M, Waldron AH, Whittaker DK (1993). *The Spitalfields project vol. 2- The Anthropology.* York: Council for British Archaeology.

Mosekilde L, Mosekilde L (1986). Normal vertebral body size and compressive strength: Relationship to age and to vertebral and iliac trabecular bone compressive strength. *Bone* 7:207-12.

Mosekilde Li, Mosekilde Le, Danielson CC (1987). Biomechanical competence of vertebral trabecular bone in relation to density and age in normal individuals. *Bone* 8:79-85.

Mosekilde Li (1989) Sex differences in age-related loss of vertebral trabecular mass and structure- biomechanical consequences. *Bone* 10:425-432.

Nash (1595). *Pierce Penniless.*

Nakamura T, Yoshikawa T, Mizuno Y, Ouchi Y, Shiraki M, Orimo H, Turner CH, Burr DB, Slemenda CV, Johnston CC (1993). Do geometric properties of the femoral neck explain Japanese American differences in hip fracture incidence? *Journal of Bone and Mineral Research* 8:333.

Nelson DA (1984). Bone density in three archaeological populations. *American Journal of Physical Anthropology* 63:198.

Nemeskéri J, Harsanyi L, Acsadi G (1960). Methoden zur diagnose des lenbensalters von skelettfunden. *Anthropologischer Anzeiger* 24:70-95.

Norušis MJ (1994). *SPSS 6.1 Guide to Data Analysis*. New Jersey: Prentice Hall Englewood Cliffs.

Orimo H, De Souza AC, Ouchi Y, Nakamura T, Shiraki M (1992). Skeletal tissue and nutrition in the ageing process an overview. *Nutrition Reviews* 50:382-4.

Ortner DJ, Putschar (1985). *Identification of Pathological Conditions in Human Skeletal Remains*. (2nd. edn.) Washington: Smithsonian Institution Press.

Parfitt AM (1976). The actions of parathyroid hormone on bone: Relation to bone remodeling and turnover, calcium homeostasis, and metabolic bone disease. Part I of IV parts: Mechanisms of calcium transfer between blood and bone and their cellular basis: morphological and kinetic approaches to bone turnover. *Metabolism* 25:809-44.

Parfitt AM, Mathews CHE, Villanueva AR, Kleerekoper M, Frame B, Rao DS (1983). Relationship between surface, volume, and thickness of iliac trabecular bone in ageing and in osteoporosis. Implications for the microanatomic and cellular mechanisms of bone loss *Journal of Clinical Investigation* 73:1396-1409.

Pate (F) D, Brown KA (1985). The stability of bone strontium in the geochemical environment. *Journal of Human Evolution* 14:483-491.

Pate DF, Hutton JT (1988). The use of soil chemistry data to address post-mortem diagenesis in bone mineral. *Journal of Archaeological Science* 15:729-739.

Pavelka MSM, Fedigan LM (1991). Menopause: A comparative life history perspective. *Yearbook of Physical Anthropology* 34:13-38.

Peck WA (1984). *Osteoporosis. National Institute of Health Consensus Development Conference Statement Online*. April 2-4. (cited 03/06/97), 5:1-6.

Peel N, Eastell R (1995). ABC of rheumatology: Osteoporosis. *British Medical Journal* 15:310 (6985):989-92.

Perzigian AJ (1973 a). Osteoporotic bone loss in two prehistoric Indian populations. *American Journal of Physical Anthropology* 39:87-96.

Perzigian AJ (1973 b). The antiquity of age-associated bone demineralization in man. *Journal of the American Geriatrics Society* 21:100-105.

Petit JL (1726). *A treatise of the diseases of the bones; containing an excellent and complete account of the nature, signs, causes and cures thereof, in all their various kinds.* (Translated from the French and Printed for Woodward T). London:

Pettier LF (1990). *Fractures a history and iconography of their treatment.* San Francisco: Norman Pub.

Phenice TW (1969). A newly developed visual method of sexing the *OS Pubis*. *American Journal of Physical Anthropology* 30:297-302.

Piepenbrink H (1986). Two example of biogenous dead bone decomposition and their consequences for taphonomic interpretation. *Journal of Archaeological Science* 13:179-193.

Pødenphant J, Herss Nielsen VA, Riis BJ, Gotfredsen A, Christiansen C (1987). Bone mass, bone structure and vertebral fractures in osteoporotic patients. *Bone* 8:127-130.

Pogrund H, Rigal WM, Makin M, Robin G, Menczel J, Steinberg R (1981). Determination of osteoporosis in patients with fractured femoral neck using the Singh index: A Jerusalem study. *Clinical Orthopaedics and Related Research* 156:189-195.

Pott P (1767). *Some Few Remarks on Fractures and Dislocations.* Printed for L. Hawes, W. Clarke and R.Collins

Prockop DJ (1992). Mutations in collagen genes as a cause of connective-tissue diseases. *New England Journal of Medicine* 20:540-546.

Rao DS (1983). Practical approach to biopsy. In (Recker RR Ed.) *Bone Histomorphometry: Techniques and Interpretation.* Boca Raton: CRC Press.

Raptis G (1992). Paleopathological investigation of osteoporosis with dual energy X-ray absorptiometry. Validation of bone mineral content determination in ancient specimens. *Orvostorteneti Kozlemenyek, Communicationes De Hisioria Artis Medicinae* 1-8:133-140.

Recker RR (1993). Prevention of osteoporosis: Calcium nutrition. *Osteoporosis International* 3 (Supl.1):S163-S5.

Reid DM (1986). Measurement of bone mass by total body calcium: A review. *Journal of the Royal Society of Medicine* 79:33-7.

Reid IR, Grey AB (1993). Corticosteroid osteoporosis. *Balliers Clinical Rheumatology,* 7:573-87.

Reid IR (1997). Establishing healthy bones in the young. *The Australian Family Physician* 26:132-4.

Rico H, Relea P, Revilla M, Herandez ER, Arribas I, Villa LF (1993). Biochemical markers of nutrition in osteoporosis. *Calcified Tissue International* 53:331-3.

Richardson ML, Genant HK, Cann CE, Ettinger B, Gordan GS, Klob FO, Reiser UJ (1985). Assessment of metabolic bone disease by quantitative computed tomography. *Clinical Orthopaedics* 195:224-38.

Richardson R (1987). *Death Dissection and the Destitute.* London: Routledge & Kegan Paul.

Riggs BL, Wahner HW, Dunn WL, Mazess RB, Offord KP, Melton LJ (III) (1981). Differential changes in bone mineral density of the appendicular and axial skeleton. *Journal of Clinical Investigation* 67:328-335.

Riggs BL, Wahner HW, Seeman E, Offord KP, Dunn WL, Mazess RB, Johnson KA, Melton LJ (III) (1982). Changes in bone mineral density of the proximal femur and spine with ageing. *Journal of Clinical Investigation* 70:716-723.

Riggs BL, Melton LJ (1983). Evidence for two distinct syndromes of involutional osteoporosis. *American Journal of Medicine* 75:899-901.

Riggs BL, Melton LJ (1986). Involutional osteoporosis. *New England Journal of Medicine* 314:1676-86.

Roberts C, Wakely J (1992). Microscopical findings associated with the diagnosis of osteoporosis in palaeopathology. *International Journal of Osteoarchaeology* 2:23-30.

Rogers MA, Evans WJ (1993). Changes in skeletal muscle with ageing effects of exercise training. *Exercize Sport Science Review* 21:65-102.

Ross HF (1986). A new comparator for SEM Stereophotogrammetry. *Scanning* 8:216-220.

Ross PD, Davis JW, Vogel JM, Wasnich RD (1990). A critical review of bone mass and the risk of fractures in osteoporosis. *Calcified Tissue International* 46:149-161.

Royal College of Physicians (1989). *Fractured Neck of Femur. Prevention and Management.* London: Royal College of Physicians.

Royle GJ, RD Speller (1991). Low angle x-ray scattering for bone analysis. *Physics in Medicine and Biology* 36:383-389.

Rudden B (1985). *The New River: A Legal History.* Oxford: Clarendon Press.

Rutherford OM, Jones DA, (1992). The relationship of muscle and bone loss and activity levels with age in women. *Age & Ageing* 21:286-93.

Sacher GA (1975). Maturation and longevity in relation to cranial capacity in hominid evolution. In (Tuttel R Ed.) *Antecedents of Man and After, Volume 1:Primates:fuctional Morphology and Evolution.* Chicago: The Hague.

Sacher GA (1976). Evaluation of the entropy and information terms governing mammalian longevity. *Interdisciplinary Topics in Gerontology* 9:69-82.

Salter M (1984). *Ageing of Bones, Appearance of Ossification Centres, Ages of Fusion.* (unpublished compilation).

Samarabandu J, Acharya R, Hausmann E, Allen K (1993). Analysis of bone x-rays using morphological fractals. *IEEE Transactions on Medical Imaging* 12:466-470.

Sambrook PN, Browne CD, Eisman JA, Bourke SJ (1988). A case of crush fracture osteoporosis from late Roman Pella in Jordan. *OSSA* 13:167-171.

Sambrook P, Kelly P, Eisman J (1993). Bone mass and ageing,. In (Reid DM Ed.) *Ballieres Clinical Rheumatology* 7:445-457. London: Balliere Tindal.

Schapira D, Schapira (1992). Osteoporosis: The evolution of a scientific term. *Osteoporosis International* 2:164-167.

Scheuer J, Black SM (1995). *The St. Bride's Documented Skeletal Collection Research report.* London: St Bride's Church.

Shaw J (1823). *On the nature and traetment of the dislocations of the spine and bones of the chest are subject, an enquiry into several modes of practice which have hitherto been followed in the treatment of dislocations.* London: Longman.

Shikata J, Yamamuro T, Iida H, Shimizu K, Yoshikawa J (1990). Surgical treatment for paraplegia resulting from vertebral fractures in senile osteoporosis. *Spine* 15:485-9.

Sillen A (1981). *Strontium & Diet at Hayonium Cave, Israel. An evaluation of the Strontium/Calcium Technique for Investigating Prehistoric diets.* Unpublished Ph.D. Dissertation.

Singh M, Nagrath AR, Maini PS (1970). Changes in the trabecular pattern of the upper end of the femur as an index of osteoporosis. *Journal of Bone and Joint Surgery* 52a: 457-67.

Slemenda CW, Miller JZ, Hui SL, Reister TK, Johnston CC (1991). Role of physical activity in the development of skeletal mass in children. *Journal of Bone Mineral Research* 6:1115-1120.

Smith RW (1847). *A Treatise on Fractures in the Vicinity of Joints and on Certain Forms of Accidental and Congenital Dislocations.* Dublin: Hodges & Smith

Smith DM, Nance WE, Kang KW, Christian JC, Johnston CC (Jr.) (1973). Genetic factors in determining bone mass. *Journal of Clinical Investigation* 52:2800-8.

Smith R (1980). Idiopathic osteoporosis in the young. *Journal of Bone and Joint Surgery* 62B:417-27.

Smith R, Stevenson JC, Winearls CG, Woods CG (1985). Osteoporosis of pregnancy. *The Lancet* May 25:1178-1180.

Sneed NV, Van Bree KM (1990). Treating ununited fractures with electricity: Nursing implications. *Journal of Gerentological Nursing* 16:26-31.

Snyder BD, Piazza S, Edwards WT, Hayes WC (1993). Role of trabecular morphology in etiology of age-related vertebral fractures. *Calcified Tissue International* 53 (Supl. 1): S14-S22.

Soames RW (1995). Skeletal Systems in (Williams PL, chairman of board) *Grays Anatomy* 35th edition. pp. 425-712. London: Churchill Livingstone.

Southard TE, Southard KA (1996). Detection of Simulated osteoporosis in maxillae using radiographic texture analysis. *IEEE Transactions on Biomedical Engineering* 42:123-132.

Sowers M (1993) The epidemiology of calcium and vitamin D in bone loss. *Journal of Nutrition* 123 (S2):465-8.

Spector TD (1991). The epidemiology of osteoporosis. In (Stevenson JC Ed.) *Osteoporosis*. Guilford: Reed Healthcare pp. 7-9.

Stevenson JC, Whitehead MI (1982). Postmenopausal osteoporosis. *British Medical Journal* 285: 585-8.

Stevenson JC, Whitehead MI (1983). Correspondence. Non-hormonal treatment of osteoporosis. *British Medical Journal* 286:1647.

Stevenson JC, Lees B, Davenport M, Cust MP, Ganger KF (1989). Determinants of bone density in normal women: Risk factors for future osteoporosis? *British Medical Journal* 298:924-928.

Stevenson JC (1991). The epidemiology of osteoporosis. In (Stevenson JC Ed.) *Osteoporosis*. Guildford: Reed Healthcare.

Stout S, Simmons DJ (1979). Use of histology in ancient bone research. *Yearbook of Physical Anthropology* pp. 228-249.

Sundick RI (1978). Human skeletal growth and age determination. *Homo* 29:228-249.

Tait L (1867). Article V.- Colles' Fracture. *Edinburgh Medical Journal* 1866-7 pp. 1107-1109.

Thompson DD (1980). Age Changes in Bone Mineralisation, cortical thickness, and Haversian canal area. *Calcified Tissue International.* 31:5-11.

Thompson DD, Slater EM, Laughlin WS (1981). Bone core analysis of Baffin Island skeletons. *Arctic Anthropology* XVIII-1:87-96.

Thompson DD, Gunness-Hey M (1981). Bone mineral-osteon analysis of Yupik-Inupiaq skeletons. *American Journal of Physical Anthropology* 55:1-7.

Thompson PW (1991). Assessment of the skeleton, In (JC Stevenson Ed.) *Osteoporosis* Guildford: Reed Healthcare. pp. 19-22.

Todd TW (1920). Age changes in the pubic bone 1: The male white pubic. *American Journal of Physical Anthropology* 3:285-34.

Ubelaker DH (1987). Estimating age at death from immature human skeletons: An overview. *Journal of Forensic Sciences* 32:1254-1263.

Ubelaker DH (1989). *Human Skeletal Remains.* 2nd edn. Taraxacum, Washington.

Vernon-Roberts B, Pirie CJ (1973). Healing trabecular microfractures in the bodies of lumbar vertebrae. *Annals of Rheumatic Disease* 32:406-412.

Virtama P, Helela T (1969). Radiographic measurement of cortical bone. Variation in a normal population between 1 and 90 years of age. *Acta Radiologica* Supplementum 293.

Wakely J, Manchester K, Roberts C (1989). Scanning electron microscope study of normal vertebrae and ribs from early Medieval human skeletons. *Journal of Archaeological Science* 16:627-642.

Waldron T (1995). *Counting The Dead. The Epidemiology of Skeletal Populations.* Chichester: John Wiley and Sons.

Walker PL (1996). Modern variation in tooth wear rates. *American Journal of Physical Anthropology* S22:237.

Ward FO (1838). *Outlines of Human Osteology.* London.

White EM, Hannus LA (1983). Chemical weathering of bone in archaeological soils. *American Antiquity* 48:316-322.

White T, Folkens P (1991). *Human Osteology*. San Francisco: Academic Press.

Woolf AD, St John Dixon A (1988). *Osteoporosis a Clinical Guide*. London: M.Dunitz.

World Health Organisation. *Assessment of fracture Risk and its application to screening for postmenopausal osteoporosis.* (1994) Report of a WHO Study Group; WHO Technical report series 843. WHO Geneva.

Wright CDP, Crawley EO, Evans WD, Garrahan NJ, Mellish RWE, Croucher PI, Compston JE (1990). The relationship between spinal trabecular bone mineral content and iliac crest trabecular bone volume. *Calcified Tissue International* 46:162-165.

Wyman J (1849). On the Cancellated Structure of the Bones of the Human Body. *Boston Journal of Natural History* 6:125-140.

Zuhrt R (1955). Stomatologische Unterschungen an Spatmittelalterlichen Funden Von Reckkahn (12-14Jh). Die Zahnkaries und ihre folgen. *Deutsche Zahn-, Munds-, und Kieferheilkunds* 25:1-15.

Appendix I
Case Histories of Fractures

The following cases are reported by R.W. Smith (1847). They are all accounts of preparations contained in the Museum of Richmond Hospital, and Richmond School of Medicine.

Case III Thomas Maguire age 84
"The fracture was caused by the patients having tripped over some slight obstacle while walking across his room; he did not fall to the ground. The patient died of irritating fever a fortnight after the occurrence of the accident."

Case IV Dorah Campbell age 75
"The injury resulted from a fall upon the hip. The woman died of suffoactive catarrh two months after the occurrence of the fracture."

Case V Mary Gill age 60
No details of circumstances of fracture.

Case VI Esther Christie age 60
No details of circumstances of fracture.

Case VII Mary Lamb age 80
"The fracture was the result of a fall upon the trochanter, and the limb was shortened 3/4 of an inch. The patient died of bronchitis and anasacca twelve months after the accident and at the period of her death the limb was 2" shorter than the other."

Case VIII Margaret Myler age 78
"The patient died twelve months after the occurrence of the accident, the prominent symptoms during the progress of the case having been insomnia, prostration of strength and occasional delirium."

Case X Female age 65
"Head of femora - the slightest pressure was sufficient to break down its structure, which was copiously infiltrated with oil; the cells of the reticular tissue were enlarged and altogether the bone presented a remarkable specimen of senile atrophy. The limb was shortened one inch and the foot elevated. The patient had been bed ridden for several years before her death."

Case XI Patrick Doolan age 60

"At the time of death (7 yrs. after the accident) shortening of the limb amounted to two inches."

Case XV Elizabeth Casey age 50

"Shortening of the limb amounted to 3/4". The patient lived for several years after receipt of injury."

Case XIX Joseph Seaton age 90

"The bone presented a remarkable example of that particular atrophy which affects the osseous system of the aged; it extended throughout the whole of the shaft, which in many places yielded to a very moderate degree of pressure; the medullary canal and the cells of the areolar tissue were enlarged and filled with a substance more resembling oil than medulla, and an unhealthy fatty deposition separated from each other the pale and atrophied fibres of the muscles around the joint. The fracture had occurred seven years before the patient's death during the whole of which period he had been bed-ridden. The limb was shortened 1 1/4 " at his decease."

Case XX Female age 65

"Patient had sustained injury several years before her death and was bed ridden from the time of the occurrence of the accident up to the period of her decease, at which time shortening of the limb amounted to 21/2"."

Case XXI Thomas Connolly aged 50

Died of a fever ten days after fracture.

Case XXII Bridget Misset age 72

"Her leg was shortened 1", there was eversion of the foot. She lived for ten weeks after the fracture."

Case XXIV Catherine Mooney age 60

"The bone was remarkably light, its compact tissue thin and its medullary canal large the interior of the head of the cervix contained several very large cells, filled with an oily medulla; several of the long bones were in a state of senile atrophy. This woman lived for five years after the occurrence of this fracture. The foot was everted and shortened by 1"."

Case XXV Robert Donovan age 80

"There was never any union of the bones, but he lived two years. At death the limb was 1 1/2" shorter."

Case XXVI Mary Woods age 70

"Foot everted, limb shortened 1". Died three months after the accident. She had a large abscess in the area."

Case XXVII Bridget Harper age 70

"Only lived ten days. The limb was shortened by half an inch and the foot was slightly everted."

Case XXVIII Female age 55

"Limb shortened 1 1/4 ". She survived several years."

Case XXIX Patrick Murphy age 80

"The leg was shortened by 2". The foot was inverted. He died fourteen days after the accident."

Case XXX Alice Harris age 70

"Five days before her admission to hospital the woman had been thrown down with great violence and having with much difficulty arisen fell a second time. the limb was shortened 1 1/2 ", she died of bronchitis ten days after the accident."

Case XXXI James Stanford age 67

"His foot was everted and was 2" shorter. Upon the fourth day after the occurrence of the accident, the patient became exceedingly restless and endeavoured to get out of bed. He died of traumatic delirium upon the eighth day from receipt of the injury. He had been a man of most intemperate habits."

Case XXXIII Mary Kelly age 56

"Her limb was shortened 1 1/4" and her foot was everted. She only lived for eleven days, her death being apparently owing to the severe shock caused by the injury."

Case XXXIV Ellen Brown age 65

"The patient died of bronchitis five days after receipt of the injury. There was no appreciable eversion, the limb was shortened by 1 1/2"."

Case XXXV Margaret Connolly age 89

"The patient, an exceedingly infirm old woman, survived the occurrence of the accident only twelve days."

Case XXXVI Thomas Murphy age 41

"The muscles around the joint were pale and flacid, and the cancelli of the femur were filled with oily fluid. The injury was the result of application of very slight force, but most of the long bones of the individual were in a very morbid state. The opposite femur was the seat of several fractures. There also existed on this side, an intracapsular fracture with complete absorption of the neck of this bone. An enormous quantity of osseous matter of an extremely porous texture, and highly vascular, was deposited throughout the entire extent of the femur; the muscles were wasted, and contained between their fibres a pale, unhealthy adeps, the bony tissue was infiltrated with oil. The patient had been bed ridden for ten years preceding his death, and during the latter part of his life he suffered great agony; he at length died of diarrhoea. The olecranon process was broken during an effort of the patient to raise himself upon his elbow in bed."

This appears to be a case of secondary osteoporosis.

Case XXXVII Male age 60

"The fracture was external to the capsule. The limb was shortened by 2". The foot was inverted. He died six months after the accident."

Case XXXVIII Male age 65

"The foot was everted, the limb was shortened 2". The man died ten days after the accident."

Case XXXIX Michael Doolan age 75

"The patient stated that about a fortnight before his admission to hospital, he had fallen upon a heap of stones upon his left hip; that he was rendered incapable of rising and was carried to hospital. He died one month after the accident."

Case XL Eliza M'Calse age 80

"She was admitted to hospital on the 13th of December 1845. She had just been violently thrown down in the street. Her limb was shortened by 1 1/4". During the night of 17th she got out of bed, and continued without assistance, to make her way across the ward to the fire, beside which she remained sitting on the floor until morning; upon several subsequent occasions she left her bed, threw her weight upon the broken limb, and hobbled about the ward, raving occasionally and unconscious of pain. Opium failed to tranquillise her; in fact she manifested most of the symptoms of traumatic delirium. When the limb was examined after several of these attempts to walk, it was found that the shortening of the limb had reached 2", and that there was a decided tendency to inversion of the foot. Upon 8th of January 1846, she was attacked with diarrhoea, and died upon 30th, six weeks later."

Case XLII Female age 60
"Her limb was shortened by 1 1/2" and her foot was everted. The patient had been knocked down with great violence. She survived the occurrence of the accident by one month."

Case XLIII Patrick Grant age 70
"As well as the fracture on examination there also seems to have been inflamation of the periosteum. The foot was everted and the limb was shortened by 1 1/2"."

Case XLIV John Summers age 74.
"The injury was caused by falling out of bed. He died two months after the accident. The limb was shortened by 1 1/2" and the foot was everted."

Case XLV Mary M'Kenna age 52
The lady died four days after the receipt of the injury.

Case XLVI Catherine Egan age 60
"The patient died of diarrhoea 1 month after the accident. The limb was shortened by 1 1/2". The foot was inverted."

Case XLVII Sarah Denny age 70
"The patient survived one month after the accident. The foot was everted and the limb was shortened by 1"."

Case XLVIII Alicai Sherlock age 68

"The patient survived three months and the foot was slightly everted. The limb was shortened by 1"."

Case L Female age 70

"The woman sustained two fractures on the same bone. Both united perfectly; the cancellated tissue (the cells of which were enlarged) was filled with oleaginous medulla, and a slight degree of pressure was sufficient to crush the structure of the head of the bone; the compact tissue of the neck of the bone had atrophied, and the portion of it which had been driven into the shaft was becoming indistinct, and, as it was resolved into cancellated tissue. The bone was remarkable for its extreme lightness. The injury was received several years before the death of the patient, who had been bedridden during the whole of the intervening time. I was unable to ascertain the amount of shortening in this case."

Case LII Bryan Dunn age 60

"There were fractures in three places. There was shortening of 1/2". The gentleman died on the fourteenth day."

Case LIII Mary Hennesy age 80

"This lady sustained two fractures. The limb was shortened by 1". The lady died in one month."

Case LVII Patrick M'Dermott age 66

"The foot was slightly everted and the leg was shortened by 1/2". He died on the sixteenth day after the receipt of the injury."

Case LVIII Female age 80

"While walking across her bedroom fell upon her left hip, and was at once rendered incapable of rising. About an hour after the receipt of injury she was seen by Dr Flemming, who found her complaining of severe pain in the region of the joint; she had lost all power over the motions of the limb; the foot was slightly inverted, and any attempt to evert it caused great pain. After six weeks patient had gained considerable command over motions of the limb, and in 7th week was able to leave her bed. Shortly after she was attacked by influenza and died eight weeks after receipt of injury."

Case LIX Man age 52

"The gentleman died sixteen days later from influenza. The bone was very vascular."

Case LX Owen Curran age 70

It is noted that the fracture healed and details are given elsewhere.

The following cases were compiled by Sir Astley Cooper and printed in "*A treatise on Dislocations and on Fractures of the Joints*" (1824 3 rd. ed.).

Case I

"Fracture of the Neck of the Thigh Bone.

Mary Clements, aged eighty-three and a half years, when walking across her room, October 1 st 1820, supported by her stick, which from the debility consequent upon old age she was obliged to employ, unperceived by herself, placed her stick in a hole in the floor, by which loosing her balance, and tottering to recover herself from falling, which she would have done but for those near her, she found she had, as she supposed dislocated her thigh-bone. When called to her she was lying upon her bed in much pain, with the thigh shortened and the foot everted. 'Examination' which fully confirmed me in the opinion that some part of the neck of the femur was broken. Her general healthy appeared nearly as good as before the accident; and she ultimately sank without any symptom of active disease, about fifteen months from the period at which the fracture took place."

Case II

"A man aged sixty-four was standing by his bed-side, when he suddenly fell to the ground, as it was supposed in a fit, and when he attempted to be raised he was unable to stand. Mr Wray was called to him, and he found his right leg some what shorter than the other, and the limb elevated. A high degree of irritative fever succeeded and on the fourth day from the accident the man died.

Upon examination of the body, great extravasation of blood was found both externally to the muscle and between them; suppuration had commenced near the trochanter major, and a fracture was found at the neck of the thigh-bone and into the trochanter, by which the neck had been received into the cancellous structure of the shaft of the bone."

Case III

"Richard Norton, aged sixty, fell upon the curb-stone of the foot pavement, and struck the upper and outer part of his left thigh with great violence. He was admitted into St. Thomas's Hospital on 24 th January 1818.

The crepitus of the trochanter major was distinctly felt in these motions, and the swelling of the parts, with the extensive crepitus, gave an idea that the accident was a comminuted state of the trochanter, and that the base of the cervix femoris was broken.

On 15th April he was placed under the physician for defect in his general health; and when he was upon the point of quitting the hospital, he was seized with spasms in his chest, of which he suddenly expired.

Upon examination ... the fracture was through the trochanter, as had been suposed, extending some way down the bone, and it apparently had united, with very slight deformity; but on maceration the head and neck of the bone became loose in the thigh-bone, and a fracture was found there, which locked the head and cervix in a shell of bone formed around them.
B. Travers."

Case from Nottingham
"Mr Oldnous, of Nottingham, who is a very intelligent surgeon, sent me two very excellent specimens of this fracture, in which the neck of the bones were broken at their junction with the trochanter major. The trochanter Major itself had also been broken off, and the trochanter Minor a little higher than its natural attatchment.

The ends of the bone were confined together by the surrounding muscles; one portion is pressed against the other, and the neck of the bone sinks deeply into the cancellated structure of the trochanter; and thus direct approximation and pressure are preserved when the fracture is at the junction of the cervix with the trochanter, and the nutrition of each extremity of the bone is well supported by the vessels which proceed to it from the surrounding parts."

Cases of Colles' Fracture (Sir Astley Cooper)
Case I
"Susannah Griffith aged seventy two, a woman from Rotherhide Poorhouse, was admitted to Guy's Hospital on 10th of April 1822. Whilst walking on the pavement, her foot had accidently slipped, and she fell with her right hand under her, in such a manner, that the palmer surface was forcably bent against the inner side of her fore arm; the carpal extremity of the ulna was consequently thrown violently outwards through the integuments, and the lower end of the radius was obliquely fractured."

Specimens from St. Bartholomew's

Lincoln's Inn Fields, February 25, 1823

My Dear Sir

We have in the museum of St. Bartholomew's, twelve specimens of fractures in the neck of the thigh bone six external to the capsule and united, and six within the capsule. In three of the latter there is no union, and in the other three there is union by ligamentous matter.

I remain dear Sir

Your's most respectfully

Edward Stanley

Edinburgh, February 17 th 1823

Letter from Alexander Monro

My dear Sir Astley

In answer to your query respecting fracture of the neck of the thigh-bone, I beg leave inform you, that I have had an opportunity of examining two cases only after death, and in both of these the broken ends of the neck of the bone were united by a substance somwhat like ligament.

I have seen several persons who had, during their lives, a fracture of the neck of the bone, but in all of them a bony re-union had not taken place.

Yours most truly

Alexander Monro.

Case from College of Surgeons

My dear sir,

Since the receipt of your letter, I have carefully examined all the specimens of fractures of the neck of the thigh-bone contained in both museums of our College of Surgeons. In that which is appropriated to the use of the school I find seven instances of fracture within the ligament.....
Conservator of the college Museum has collected five specimens of fractures within the ligament. In the museum are also four instances of fracture external to the condyle ligament. In the school museum are two instances of fracture external to the ligament. Of this latter description of fracture less than one half the number are united by bony union.

Of the fractures within the ligament, not one has made a nearer approach to bony union. I must say I have never yet seen an instance of bony union where the fracture had been within the ligament. We have many specimens of a disease of the head and neck of the thigh-bone, which is of frequent occurrence among our labouring poor.

I am my dear Sir

Your most sincere friend,

A. Colles.

Cases Compiled by J. Amesbury "Remarks on the nature and treatment of fractures of the trunk and extremities" Vol. I. (1831).

Mr K. aged 72,

"In descending four steps from a neighbour's door came suddenly on the pavement, and fell against the cub-stone, and was instantly so much hurt as to be unable to move from the place.

Upon examination, the limb was found shortened; the right knee and foot were turned outward; and the whole limb appeared loose, as if it had lost its support from the upper joint."

Sarah Gibson, aet. 90

"Fell on the 9 th of January, from a high stool on which she was sitting, upon the left hip, and being a heavy, suffered considerable injury considerable contusion having been sustained by the part, which was very painfull and swelled. The limb was rather more than half an inch shorter than the other, and the great toe turned inwards, in a manner sufficiently marked, although not quite so decidedly as in a case of dislocation.

The patient died 44 days after the accident and on dissection a fracture was discovered external to the capsular ligament."

Hannah Johnson aet. 67,

"Was admitted under my care at the dispensary, having a fracture of the cervix femoris.... Upon inquiry I found that, five weeks before her application to the Dispensary, she fell off a step and pitched with great violence upon the left side. She was taken up, unable to bear upon the limb - suffering considerable pain at the upper and inner part of the thigh. Crepitus was felt with difficulty."

Letter of unknown origin

18 th August 1828

Dear Sir

I send you particulars of a case of a fracture of the upper third of the thigh bone which occured in an old lady in her 74 th. year.

In the evening of Sunday 6th April, of the present year, I was summoned to attend upon an old lady, who had met with serious injury, in consequence of being pushed down by some boys. On my arrival she complained of great pain in the left thigh and hip; and, upon turning the bed clothes off the affected side, an immense tumour presented itself at the upper part of the thigh, which I found to be the result of a transverse fracture of the femur, immediately below the trochanter minor. The limb was shortened an inch and a half, and the foot was turned inward. (Six weeks later) she rapidly sunk, and died on the fourth day.

Notes taken from St. Bartholomew's Pathology Museum.

Record No. 925
"Sections of the upper part of a femur fractured almost vertically through the neck, at the base of the head and entirely within the capsule. The neck and the upper part of the shaft have been drawn a little upwards, and the lower part of the fractured surface and margin of the neck has been driven tightly into the cancellous tissue of the head. In this position, without any lateral displacement, and without any absorption of the neck of the femur, the fractured surfaces have been united by a thin layer of tough fibrous tissue, which permitted them to be slightly moved on one another. The fibrous covering of the neck appears to have been torn across and reunited in front, but to have remained entire behind. All the textures adjacent to the fracture are healthy, but the walls of the bones are thin, and its cancellous soft tissue is atrophied and full of soft fat."

839.
"1831-1846 the patient was a very old woman. The fracture occured about three months before death. (Wet Specimen)."

A.873 Malunion
"A radius and ulna, both of which have been fractured about 3" above their carpal ends. The ends of the bones overlap and have united in this position. 1831-1846 (Dry Preparation)."

A. 878 Colles' Fracture
"The radius has been fractured a little more than an inch above its carpal end. Union is firm. 1831-1846."

A. 879 Colles' Fracture, Malunion.
"At carpal end of radius there had been a transverse fracture immediately above the line of the epiphysis, and the posterior or dorsal margin of the upper fragment has been driven into the cancellous tissue of the lower one. The fracture is united, and a buttress of new bone has formed on the dorsal and radial sides of the displaced portions. (1831-1846)."

A. 880 Colle's Fracture Malunion.
"The radius has been broken about 3/4 of an inch above its lower end. The fracture is united, with the lower portion of bone displaced towards the radial and dorsal aspect of the upper portion. (1831-1846). Dry Preparation."

A. 3
"The bodies of four dorsal and lumbar vertebrae, which have been deeply hollowed out by absorption consequent on the pressure of an aneurysm of the aorta. The surface of bone formed part of the aneurysmial sac, and layers of fibre still adhere to it. It will be observed that the intervertebral fibro-cartilages and contiguous edges of the bones are entire. 1831 (Seen, not particularly wedged looking)."

A. 27 Atrophy (Senile)
"Sections of the upper part of a femur from a very aged woman. Its texture is remarkably soft and light, and contains an abundance of soft fatty matter which in maceration, has assumed the appearance of adipocere. The walls of the femur are at the thickest part not more than a line in thickness; the neck is shortened and it is rather less oblique than is natural; the head is reduced in size, ands irregularly flattened. There has been a fracture of the neck of the bone, which has united. 1831-1846." (Seen trabeculae are very fine and spindly - not in liquid).

A.951 Non-union (Fibrous)
"Section of the head and neck of a femur, showing white lines of fibrous tissue marking the site of union of a previous fracture of the neck. 1823"

A.932 Closed (Impacted) Fracture.
"A specimen of impacted fracture of the neck of the femur. from an old man, aged 84 who lived for two years after the injury. Presented by Tony Hester Esq. (Dry Specimen)."

A.951 Non-Union. False Joint.
"Sections of the head and neck of a femur, showing white lines of fibrous tissue marking the site of union of a previous fracture of the neck. 1823. The specimen was taken from a body supplied for dissection. No history could be obtained."

Appendix II

Demographic Data Obtained From Death Registers

Farringdon Street - Age at Death From Death Registers								
Males	Femals	Males	Females	Males	Females	Males	Females	Males
15	15	26	28	34	38	40	44	49
15	15	27	28	34	39	40	44	49
16	16	27	28	34	39	40	44	49
16	17	27	28	34	39	41	44	49
16	17	27	29	34	39	41	44	49
16	18	27	29	34	40	41	44	49
17	18	27	30	35	40	41	45	50
17	18	27	30	35	40	41	45	50
17	18	28	30	35	40	41	45	50
18	19	28	30	35	40	41	45	50
18	19	28	30	35	40	42	45	50
19	19	28	30	35	40	42	45	50
19	19	28	30	35	40	42	45	50
19	20	28	30	35	40	42	46	50
19	20	29	30	35	40	42	46	50
20	20	29	31	35	40	42	46	50
20	20	29	31	36	40	42	46	50
21	20	29	32	36	40	42	46	50
21	21	29	32	36	40	42	46	51
21	21	30	32	36	40	43	46	51
21	21	30	32	36	41	43	47	51
21	22	30	32	36	41	43	47	51
22	22	30	32	36	41	43	48	52
22	22	30	32	36	41	44	48	52
22	22	30	32	36	41	44	48	52
22	22	30	33	36	41	44	48	52
22	23	30	33	36	41	44	48	53
22	23	30	33	36	41	44	48	53
23	23	30	33	36	42	44	48	53
23	23	30	33	36	42	45	48	53
23	24	30	33	37	42	45	48	53
23	24	30	34	37	42	45	48	53
23	24	31	34	37	42	45	49	53
23	24	31	34	37	42	45	49	53
23	24	31	35	37	42	45	49	53
23	24	31	35	38	42	45	49	53
24	25	31	35	38	42	45	49	53
24	25	32	35	38	42	46	49	53
24	25	32	35	38	42	46	49	53
24	25	32	35	38	42	46	50	53
24	25	32	35	38	42	46	50	54
24	26	32	35	39	42	47	50	54
24	26	33	35	39	42	47	50	54
25	26	33	36	39	43	47	50	54
25	26	33	36	39	43	48	50	54
25	26	33	36	40	43	48	50	54
25	27	33	36	40	43	48	50	54
25	27	33	37	40	43	48	50	55
25	28	34	37	40	43	48	50	55
25	28	34	37	40	43	48	50	55

Continued overleaf

Farringdon Street - Age at Death From Death Registers								
Females	Males	Females	Males	Females	Males	Females	Males	Females
25	55	34	37	40	44	48	50	55
26	55	34	38	40	44	49	50	55
50	56	57	61	62	69	70	83	81
50	56	57	61	63	69	70	83	81
50	56	57	62	63	69	70	83	82
51	56	57	62	64	69	70	87	82
51	56	57	62	64	70	70	88	82
51	56	57	62	64	70	70	88	82
51	56	58	62	64	70	70	88	82
52	57	58	62	64	70	70	88	82
52	57	58	62	64	70	70	89	83
52	57	58	62	64	70	70	90	83
52	57	59	62	64	70	70	94	84
52	57	59	62	64	70	70	96	84
52	57	60	63	64	70	70	98	84
52	57	60	63	65	70	70	99	84
52	58	60	63	65	71	71	99	84
52	58	60	63	65	71	71		84
53	58	60	63	65	71	72		84
53	58	60	63	65	72	72		84
53	58	60	63	65	72	72		85
53	58	60	63	66	72	73		85
53	58	60	63	66	72	73		87
53	58	60	64	66	72	73		88
53	58	60	64	66	73	73		88
53	59	60	64	66	73	73		88
53	59	60	64	66	73	73		89
53	59	60	65	66	73	74		90
54	59	60	65	66	73	74		90
54	59	60	65	67	74	74		
54	60	60	65	67	74	74		
54	60	60	65	67	74	74		
54	60	60	65	67	74	74		
54	60	60	66	67	74	75		
54	60	61	66	67	75	75		
55	60	61	66	67	76	76		
55	60	61	66	67	76	76		
55	60	61	66	67	77	76		
55	60	61	66	68	77	77		
55	60	61	66	68	77	77		
55	60	62	67	68	77	77		
55	60	62	67	68	78	77		
55	60	62	67	69	79	77		
55	60	62	67	69	79	77		
55	60	62	67	69	80	77		
56	60	62	67	69	80	78		
56	60	62	67	69	80	78		
56	60	62	67	69	81	79		
56	61	62	67	69	81	80		
57	61	62	67	69	82	80		
57	61	62	68	69	82	80		
57		62	68	69	82	80		
57		62	68	70	83	80		

Table ii.1 Data obtained on age at death from Farringdon Street death registers 1739-1825.

Redcross Way - Age at Death From Death Registers							
Males	Females	Males	Females	Males	Females	Males	Females
13	15	39	42	56	64	80	64
14	18	39	43	56	64	84	64
14	18	39	43	57	64	88	81
15	18	40	43	57	65	91	82
16	18	40	44	58	65	95	84
17	19	40	44	58	65		86
20	22	40	45	59	65		86
21	22	40	45	59	66		88
21	22	40	45	59	66		92
21	22	40	46	60	67		96
22	23	41	48	60	67		
22	25	41	48	60	68		
23	25	43	48	60	68		
25	26	44	49	60	69		
25	27	44	50	61	69		
26	29	44	50	61	70		
26	30	45	50	61	70		
26	30	45	51	62	70		
27	31	45	52	62	70		
27	32	45	53	62	70		
28	32	45	53	63	70		
28	33	45	53	63	70		
29	36	46	54	63	71		
29	37	46	55	64	72		
29	37	47	55	64	72		
29	37	47	56	65	72		
30	37	47	56	66	72		
31	38	48	56	66	72		
32	38	48	57	67	72		
33	38	49	57	68	73		
33	39	50	57	68	73		
33	39	50	58	68	73		
34	39	50	59	69	74		
34	40	50	59	70	74		
34	40	52	60	70	75		
35	40	52	60	70	75		
35	40	52	60	71	75		
36	40	53	60	71	75		
36	40	54	60	71	76		
36	40	54	60	74	76		
36	40	54	61	75	76		
37	41	55	61	75	77		
37	41	55	63	75	78		
37	41	55	63	78	78		
38	42	55	63	78	79		
38	42	56	63	79	80		
38	42	56	64	80	81		

ii.2 Data obtained on age at death from Redcross Way death registers 1789-1790.

St Bride's - Age at Death From Death Registers				
Male	Female	Male	Female	Male
17	18	54	60	74
17	19	55	60	75
20	21	55	61	75
20	23	56	61	75
21	23	56	61	77
21	24	56	61	77
22	25	56	62	77
22	27	58	62	78
23	28	58	62	80
24	28	58	63	80
25	28	59	63	82
25	29	59	63	82
25	29	59	63	83
25	30	60	63	88
27	31	60	63	
27	32	60	64	
28	32	62	64	
28	34	62	64	
29	36	62	65	
31	36	62	65	
31	37	63	66	
32	37	63	67	
33	39	63	67	
33	42	63	67	
34	42	63	69	
34	43	64	69	
35	43	64	69	
36	44	64	70	
36	44	64	70	
37	45	65	70	
38	45	65	70	
39	46	66	71	
41	46	66	72	
41	49	66	73	
42	51	66	77	
43	51	66	77	
45	54	68	77	
46	54	68	78	
46	55	69	78	
47	55	69	79	
47	57	69	79	
48	58	69	81	
50	58	70	82	
51	58	70	84	
51	58	71	87	
52	59	72	90	
53	60	72	91	
53	60	74		

ii.3 Data obtained on age at death from St Bride's report (Scheuer and Black 1995).

Appendix III

Primary Data For Techniques Used On Redcross Way And Farringdon Street Sample Material

Key for Tables 1 - 25

Age Category (score)	Age in Years
u	of unknown age
0	<15
1	15-25
2	26-35
3	36-45
4	46+

Sex (score)	Sex
1	Male
2	Female
3	Ambiguous

iii.1 Femoral Base-line Bone Density Data - Redcross Way

Skel. No.	Age Score	Sex Score	Femur Whole Density	Femur Trabecular Density
2	1	1	-	-
6	4	1	-	-
9	3	1	-	-
11	4	1	0.5890	0.2134
24	2	2	0.5474	0.1493
26	4	2	0.5151	0.2731
28	4	2	0.5609	0.3011
32	4	2	0.5135	0.0933
34	u	3	-	-
44	4	3	0.4826	0.1000
46	1	1	0.6868	0.3875
48	4	2	-	-
52	4	2	0.6321	0.1181
54	2	1	0.6470	0.3597
56	3	2	0.6064	0.1931
60	4	1	0.8001	0.3366
62	4	1	0.5070	0.0583
64	4	2	-	-
72	4	2	0.4406	0.0614
89	2	2	0.8124	0.2212
91	4	1	0.5528	0.0767
92	u	3	-	-
96	2	2	0.5142	0.1734
99	2	2	-	-
100	4	2	0.6683	0.3831
101	3	2	0.6819	0.187
114	4	1	0.2138	0.1100
116	3	2	0.4933	0.1292
118	3	2	-	-
119	4	1	0.5419	0.2275
120	u	3	-	-
122	4	2	-	-
136	1	2	0.7663	0.2284
137	2	1	0.5880	0.3412
140	2	2	0.8450	0.2839
150	4	2	-	-
155	3	1	0.5147	0.1447
157	4	2	0.4572	0.1775
159	4	2	0.3688	0.1066
161	4	1	0.8141	0.0757
165	3	1	0.6259	0.2973
167	2	1	0.6664	0.2714
169	2	3	-	-
171	4	1	-	-
175	4	1	0.6634	0.2563
no number	4	1	0.4170	0.0683

Table iii.1 Redcross Way, whole and trabecular bone density g cm^{-3} obtained from the femoral necks.

iii.2 Vertebral Base-line Bone Density Data - Redcross Way

Skel. No.	Age Score	Sex Score	Vertebral Whole Density	Vertebral Trabecular Density
2	1	1	-	-
6	4	1	-	-
9	3	1	-	-
11	4	1	0.2918	0.2246
24	2	2	0.2801	0.1750
26	4	2	-	-
28	4	2	0.2055	0.1638
32	4	2	-	-
34	u	3	-	-
44	4	3	0.2881	0.2046
46	1	1	0.3599	0.2888
48	4	2	-	-
52	4	2	-	-
54	2	1	0.4208	0.4188
56	3	2	0.3475	0.2535
60	4	1	0.4636	0.3252
62	4	1	0.2801	0.1635
64	4	2	-	-
72	4	2	-	-
89	2	2	0.3692	0.3032
91	4	1	0.2416	0.1976
92	u	3	-	-
96	2	2	0.2741	0.2063
99	2	2	-	-
100	4	2	0.3448	0.2909
101	3	2	-	-
114	4	1	-	-
116	3	2	0.2557	0.2070
118	3	2	0.1875	0.1439
119	4	1	0.2941	0.2721
120	u	3	-	-
122	4	2	-	-
136	1	2	0.4312	0.4403
137	2	1	-	-
140	2	2	0.4470	0.4566
150	4	2	0.3092	0.1843
155	3	1	0.2728	0.2191
157	4	2	0.4180	-
159	4	2	0.2579	0.1792
161	4	1	0.3316	0.2013
165	3	1	0.4113	0.3275
167	2	1	0.3438	0.2428
169	2	3	-	-
171	4	1	-	-
175	4	1	0.3779	0.3055
no number	4	1	0.2040	0.1324

Table iii.2 Redcross Way, whole and trabecular bone density g cm^{-3} obtained from the vertebral bodies.

iii.3 Radius Base-line Bone Density Data - Redcross Way

Skel. No.	Age Score	Sex Score	Radius Whole Density
2	1	1	-
6	4	1	0.5394
9	3	1	0.5382
11	4	1	0.6128
24	2	2	0.4774
26	4	2	0.4493
28	4	2	-
32	4	2	0.2873
34	u	3	-
44	4	3	0.5070
46	1	1	0.5920
48	4	2	0.2554
52	4	2	0.5148
54	2	1	0.7925
56	3	2	-
60	4	1	0.8149
62	4	1	-
64	4	2	-
72	4	2	0.2461
89	2	2	0.6489
91	4	1	-
92	u	3	-
96	2	2	-
99	2	2	-
100	4	2	-
101	3	2	0.5809
114	4	1	-
116	3	2	-
118	3	2	0.3655
119	4	1	0.4695
120	u	3	-
122	4	2	-
136	1	2	-
137	2	1	0.7608
140	2	2	0.6433
150	4	2	0.3971
155	3	1	-
157	4	2	0.3270
159	4	2	-
161	4	1	0.5426
165	3	1	0.7042
167	2	1	0.6974
169	2	3	-
171	4	1	-
175	4	1	0.5622
no number.	4	1	-

Table iii.3 Redcross Way, whole bone density g cm^{-3} obtained from radii.

iii.4 Iliac Crest Base-line Bone Density Data - Redcross Way

Skel. No.	Age Score	Sex Score	Iliac Crest Density
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	-
24	2	2	0.5661
26	4	2	-
28	4	2	0.5962
32	4	2	0.4600
34	u	3	-
44	4	3	-
46	1	1	0.6357
48	4	2	-
52	4	2	-
54	2	1	0.8504
56	3	2	0.4916
60	4	1	-
62	4	1	0.5820
64	4	2	-
72	4	2	-
89	2	2	0.8199
91	4	1	0.4401
92	u	3	-
96	2	2	0.5939
99	2	2	-
100	4	2	0.6810
101	3	2	0.7179
114	4	1	1.1711
116	3	2	0.4425
118	3	2	-
119	4	1	-
120	u	3	-
122	4	2	-
136	1	2	0.7556
137	2	1	0.7627
140	2	2	0.8355
150	4	2	0.7381
155	3	1	0.6192
157	4	2	-
159	4	2	-
161	4	1	-
165	3	1	0.7634
167	2	1	0.6806
169	2	3	-
171	4	1	-
175	4	1	0.8056
no number	4	1	-

Table iii.4 Redcross Way, whole bone density g cm^{-3} obtained from ilia.

iii.5 Vertebral Base-line Density Data - Farringdon Street (Individuals < 25 Years of Age)

Skel. No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density
1791	0	3	0.3851	-
2114	1	3	0.6269	-
1204	1	3	0.3414	0.3396
1357	1	3	0.3665	-
1693	1	3	0.2536	0.2039
2245	1	3	0.3034	-
1202	1	3	0.2636	-
1819	1	3	0.3651	-

Table iii.5 Farringdon Street, whole and trabecular bone density (g cm^{-3}) obtained from vertebral bodies of individuals <25 years of age

iii.6 Vertebral Body Base-line Density Data - Farringdon Street (Females of Unknown Age)

Skel. No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density.
1564	u	2	0.4310	0.4018
1570	u	2	0.2923	0.2454
1152	u	2	0.2863	0.1946
1787	u	2	0.3910	0.3605
1634	u	2	0.2965	0.2393
1891	u	2	0.3480	-
1422	u	2	0.4012	0.2997
2005	u	2	0.3363	-
2055	u	2	0.4754	-

Table iii.6 Farringdon Street, whole and trabecular bone density (g cm^{-3}), obtained from vertebral bodies of females of unknown age

iii.7 Vertebral Body Density Data - Farringdon Street (Males of Unknown Age)

Skel. No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density.
1170	u	1	0.4845	-
1831	u	1	0.2687	-
1870	u	1	0.2799	0.2068
1689	u	1	0.2689	0.2197
1621	u	1	0.3538	0.3363

Table iii.7 Farringdon Street, whole and trabecular bone density (g cm^{-3}) obtained from vertebral bodies of males of unknown age.

iii.8 Vertebral Body Base-line Density Data - Farringdon Street (Individuals of Unknown Age or Sex)

Slice No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density
1178	u	3	0.2659	0.2220
1215	u	3	0.2930	0.2671
2214	u	3	0.3083	0.2199
1546	u	3	0.3100	-
1995	u	3	0.3874	0.3681
1745	u	3	0.3590	-

Table iii.8 Farringdon Street, whole and trabecular bone density (g cm^{-3}), obtained from vertebral bodies of individuals of unknown age or sex.

iii.9 Vertebral Body Base-line Density Data - Farringdon Street Females

Skel. No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density
1278	2	2	0.3336	0.3122
2223	2	2	0.3139	0.2087
2383	2	2	0.3229	-
1793	2	2	0.445	0.4096
1809	2	2	0.3305	0.1393
2161	2	2	0.4773	0.4888
2199	2	2	0.4168	0.3337
1899	2	2	0.3124	0.2680
1903	2	2	0.4228	0.3546
1653	2	2	0.5063	0.3938
1755	2	2	0.5158	0.4735
1781	2	2	0.3495	-
1952	2	2	0.3477	0.3035
1990	2	2	0.2979	0.2412
1934	2	2	0.2848	0.2770
1938	2	2	0.4528	-
2073	2	2	0.3183	-
2134	2	2	0.2884	0.2425
1119	3	2	0.2811	0.2188
1123	3	2	0.1441	-
1281	3	2	0.3305	-
1366	3	2	0.3340	0.3406
1379	3	2	0.2602	-
1428	3	2	0.3300	0.2911
1586	3	2	0.3847	0.2836
1610	3	2	0.3384	-
1611	3	2	0.4524	0.3341
1649	3	2	0.3909	-
1709	3	2	0.3229	-
1897	3	2	0.2041	-
2116	3	2	0.3005	-
2122	3	2	0.2507	-
2049	3	2	0.3100	0.2990
2136	3	2	0.2518	-
1589	2/3	2	0.5184	0.3706

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Skel. No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density
2302	2/3	2	0.5700	-
1753	2/3	2	0.2559	-
1799	2/3	2	0.3661	0.3147
2206	2/3	2	0.2034	0.1461
1336	2/3	2	0.3876	0.3607
1188	2/3	2	0.3814	-
2105	4	2	0.2508	0.2025
1954	4	2	0.1795	0.1005
1707	4	2	0.1916	0.1773
1771	4	2	0.2644	0.1653
1637	4	2	0.3019	-
1671	4	2	0.2634	-
1691	4	2	0.1463	-
1874	4	2	0.2270	-
1913	4	2	0.2189	0.2217
2132	4	2	0.2513	-
2158	4	2	0.3730	-
2216	4	2	0.4396	0.4022
2233	4	2	0.4449	-
2237	4	2	0.2643	-
1174	4	2	0.2655	-
1343	4	2	0.3666	0.2825
1350	4	2	0.2496	0.0667
1203	4	2	0.4970	-
1127	4	2	0.2866	-
1209	4	2	0.2449	0.1905
1409	4	2	0.3306	0.2698
1417	4	2	0.2754	-
1441	4	2	0.2615	-
1326	4	2	0.2698	-
2083	4	2	0.2817	-

Table iii.9 Farringdon Street, whole and trabecular bone density (g cm^{-3}) obtained from vertebral bodies of females 26-46+ years of age

iii.10 Vertebral Body Base-line Density Data - Farringdon Street Males

Skel. No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density.
1247	2	1	0.4732	0.4368
2165	2	1	0.3446	-
1330	2	1	-	0.2079
1519	2	1	0.2673	0.2556
1578	2	1	0.2955	-
1580	2	1	0.5055	-
1599	2	1	0.3146	0.2858
1727	2	1	-	0.3109
1767	2	1	0.3914	0.3556
1860	2	1	0.2947	-
1845	2	1	0.4818	-
1893	2	1	0.3885	0.3478
2140	2	1	0.2884	0.2755
1957	2	1	0.4494	0.4018
1972	2	1	0.3881	-
1549	2	1	0.4325	-
1116	2	1	0.3660	-
2085	2	1	0.3417	-
1456	2	1	0.4321	0.4433
1449	3	1	0.3245	-
1390	3	1	0.2665	0.2465
1408	3	1	0.2641	-
1415	3	1	0.4568	-
1251	3	1	0.2985	0.1870
1291	3	1	0.3525	0.1050
1292	3	1	0.3561	0.1365
1298	3	1	0.2532	0.2645
1515	3	1	0.3964	0.2527
1673	3	1		-
1200	3	1	0.2964	0.1958
1853	3	1	0.3623	-
2298	3	1	0.3314	-
2043	3	1		0.2268
2053	3	1	0.2734	-
2340	3	1	0.4241	-
2205	3	1	0.3841	-
2081	3	1	0.4524	-
2126	3	1	0.2583	-

Continued overleaf

Skel. No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density.
2130	3	1	0.3063	0.2518
2164	3	1	0.2813	0.2687
1925	3	1	0.2733	0.2868
1930	3	1	0.3126	0.1472
2342	2/3	1	0.3879	-
1879	2/3	1	0.5050	-
1999	2/3	1	0.3170	-
2075	2/3	1	0.4243	0.3162
1420	2/3	1	0.4311	0.3383
1454	2/3	1	0.4245	-
2185	4	1	0.3232	-
2193	4	1	0.2643	-
2195	4	1	0.5130	-
2243	4	1	0.3227	0.2320
1739	4	1	0.4203	-
1743	4	1	0.4105	0.3125
2058	4	1	0.3884	-
2061	4	1	0.4785	0.4005
2063	4	1	0.2649	-
1862	4	1	0.3516	-
1872	4	1	0.4404	0.3800
1457	4	1	0.4306	0.4614
1500	4	1	0.3353	-
1825	4	1	0.3232	-
1827	4	1	0.3052	-
1785	4	1	0.3046	0.2562
1795	4	1	0.2800	0.2160
1591	4	1	0.4179	0.4167
2109	4	1	0.3253	-
2120	4	1	0.2811	-
2124	4	1	0.3314	0.3074
1521	4	1	0.3173	-
1525	4	1	0.3420	-
2001	4	1	0.3073	0.2573
2011	4	1	0.3081	-
1976	4	1	0.3664	-
1991	4	1	0.3346	0.2567
1997	4	1	0.2769	-

Continued overleaf

Skel. No.	Age	Sex	Vertebral Whole Density	Vertebral Trabecular Density.
1942	4	1	0.2478	-
2077	4	1	0.3429	0.2513
1312	4	1	0.3165	0.2755
1125	4	1	0.2470	-
1126	4	1	0.3287	0.2598
1155	4	1	0.3559	0.2965
2312	4	1	0.4704	0.3327
2332	4	1	0.3312	-
2253	4	1	0.4008	0.3187
2263	4	1	0.4328	-
2269	4	1	0.2933	-
2288	4	1	0.2924	-
1606	4	1	0.3956	-
1608	4	1	0.3731	0.3187
1635	4	1	0.3679	0.2641
1685	4	1	0.2551	-
1695	4	1	0.2228	-

Table iii.10 Farringdon Street, whole and trabecular bone density (g cm^{-3}), obtained from vertebral bodies of males of aged 26-46+ years of age.

iii.11 Femoral Neck DEXA Scans - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Femur.
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	0.1225
24	2	2	0.0945
26	4	2	0.1050
28	4	2	0.2390
32	4	2	0.0560
34	u	3	-
44	4	3	0.1560
46	1	1	0.5365
48	4	2	-
52	4	2	0.2205
54	2	1	0.2190
56	3	2	0.1385
60	4	1	0.2250
62	4	1	0.0315
64	4	2	-
72	4	2	0.0525
89	2	2	0.1845
91	4	1	0.0595
92	u	3	-
96	2	2	0.1655
99	2	2	-
100	4	2	0.2590
101	3	2	0.0925
114	4	1	0.0830
116	3	2	-
118	3	2	-
119	4	1	0.0840
120	u	3	-
122	4	2	-
136	1	2	0.4410
137	2	1	0.3860
140	2	2	0.2030
150	4	2	-
155	3	1	0.1275
157	4	2	0.0585
159	4	2	0.0260
161	4	1	0.1185
165	3	1	0.1125
167	2	1	0.2255
169	2	3	-
171	4	1	-
175	4	1	0.1660
no number.	4	1	0

Table iii.11 Data obtained from DEXA scans of Redcross Way femoral necks(g cm^{-2}).

iii.12 Vertebral Body DEXA scans - Redcross Way

Skel. no.	Age Score	Sex Score	Bone Mineral Density Vertebrae
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	0.0375
24	2	2	0.0380
26	4	2	-
28	4	2	0
32	4	2	0
34	u	3	-
44	4	3	0.0545
46	1	1	0.0490
48	4	2	-
52	4	2	-
54	2	1	0.0695
56	3	2	0.0410
60	4	1	0.0535
62	4	1	0
64	4	2	-
72	4	2	-
89	2	2	0.0615
91	4	1	0
92	u	3	-
96	2	2	0.0280
100	2	2	0.0030
101	4	2	-
114	3	2	-
116	4	1	0.0230
118	3	2	0
119	3	2	0.0605
120	4	1	-
122	u	3	-
136	4	2	0.0625
137	1	2	0.0625
140	2	1	0.0640
150	2	2	0
155	4	2	0.0275
156	3	1	-
157	4	2	0
159	4	2	0
161	4	1	0.0250
165	3	1	0.0905
167	2	1	0.0480
169	2	3	-
171	4	1	-
175	4	1	0.0815
no number	4	1	0

Table iii.12 Data obtained from DEXA scans of Redcross Way vertebral bodies. (g cm-^{2}).

iii.13 Radius DEXA Scans - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Radii
2	1	1	
6	4	1	0.0705
9	3	1	0.0620
11	4	1	0.1015
24	2	2	0.0055
26	4	2	0
28	4	2	0.0035
32	4	2	1.0008
34	u	3	
44	4	3	0.0710
46	1	1	0.1545
48	4	2	0
52	4	2	0
54	2	1	0.182
56	3	2	-
60	4	1	0.1425
62	4	1	-
64	4	2	-
72	4	2	0
89	2	2	0.0090
91	4	1	-
92	u	3	-
96	2	2	-
99	2	2	-
100	4	2	0
101	3	2	0.0093
114	4	1	0.0975
116	3	2	-
118	3	2	0
119	4	1	0.0185
120	u	3	-
122	4	2	-
136	1	2	-
137	2	1	0.2050
140	2	2	0.0455
150	4	2	0
155	3	1	-
157	4	2	0
159	4	2	-
161	4	1	0.0415
165	3	1	0.2420
167	2	1	0.1400
169	2	3	-
171	4	1	-
175	4	1	0.0910
no number	4	1	0.0470

Table iii.13 Data obtained from DEXA scans of Redcross Way radius (g cm-^{2}).

iii.14 Iliac Crest DEXA Scans - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Iliac Crest
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	0.0300
24	2	2	0.0495
26	4	2	-
28	4	2	0.0350
32	4	2	0.0110
34	u	3	-
44	4	3	-
46	1	1	0.0740
48	4	2	-
52	4	2	-
54	2	1	0.0880
56	3	2	0.0180
60	4	1	-
62	4	1	0.0470
64	4	2	-
72	4	2	-
89	2	2	0.0855
91	4	1	0.0265
92	u	3	-
96	2	2	0.0630
99	2	2	-
100	4	2	0.0960
101	3	2	0.0555
114	4	1	0.0640
116	3	2	0
118	3	2	-
119	4	1	-
120	u	3	-
122	4	2	-
136	1	2	0.0675
137	2	1	0.0530
140	2	2	0.0825
150	4	2	0.0225
155	3	1	0.0780
157	4	2	-
159	4	2	-
161	4	1	-
165	3	1	0.0695
167	2	1	0.0400
169	2	3	-
171	4	1	-
175	4	1	0.0970
no number	4	1	-

Table iii.14 Data obtained from DEXA scans of Redcross Way ilia (g cm-^{2}).

iii.15 Femoral Neck LAXS Scans - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Femur
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	159033
24	2	2	165595
26	4	2	173603
28	4	2	180310
32	4	2	101327
34	u	3	-
44	4	3	-
46	1	1	272469
48	4	2	-
52	4	2	163846
54	2	1	233604
56	3	2	109011
60	4	1	319227
62	4	1	57009
64	4	2	-
72	4	2	59409
89	2	2	236362
91	4	1	87423
92	u	3	-
96	2	2	137810
99	2	2	-
100	4	2	304590
101	3	2	190428
114	4	1	98781
116	3	2	-
118	3	2	-
119	4	1	159825
120	u	3	-
122	4	2	-
136	1	2	258019
137	2	1	243183
140	2	2	314477
150	4	2	-
155	3	1	84149
157	4	2	137452
159	4	2	72146
161	4	1	151312
165	3	1	181812
167	2	1	185244
169	2	3	-
171	4	1	-
175	4	1	168024
no number	4	1	408450

Table iii.15 Data obtained from LAXS scans (photon counts), of Redcross Way femoral necks.

iii.16 Vertebral Body LAXS Scans - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Vertebrae
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	56443
24	2	2	52277
26	4	2	-
28	4	2	39640
32	4	2	-
34	u	3	-
44	4	3	47286
46	1	1	65754
48	4	2	-
52	4	2	-
54	2	1	90098
56	3	2	60219
60	4	1	65205
62	4	1	52597
64	4	2	-
72	4	2	-
89	2	2	74340
91	4	1	58313
92	u	3	-
96	2	2	50078
99	2	2	-
100	4	2	60927
101	3	2	-
114	4	1	-
116	3	2	56521
118	3	2	37929
119	4	1	55209
120	u	3	-
122	4	2	-
136	1	2	11442
137	2	1	-
140	2	2	-
150	4	2	44201
155	3	1	61247
157	4	2	-
159	4	2	36274
161	4	1	61163
165	3	1	71883
167	2	1	59038
169	2	3	-
171	4	1	-
175	4	1	71299
no number	4	1	32189

Table iii.16 Data obtained from LAXS scans (photon counts), of Redcross Way vertebral bodies.

iii.17 Femoral Neck Optical Densitometry - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Femur
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	6.609
24	2	2	4.279
26	4	2	4.813
28	4	2	5.711
32	4	2	4.188
34	u	3	-
44	4	3	5.633
46	1	1	9.367
48	4	2	-
52	4	2	4.461
54	2	1	8.756
56	3	2	4.644
60	4	1	10.825
62	4	1	4.422
64	4	2	-
72	4	2	3.342
89	2	2	6.637
91	4	1	4.331
92	u	3	-
96	2	2	5.190
99	2	2	-
100	4	2	6.934
101	3	2	6.583
114	4	1	4.774
116	3	2	-
118	3	2	-
119	4	1	6.361
120	u	3	-
122	4	2	-
136	1	2	7.298
137	2	1	8.821
140	2	2	7.598
150	4	2	-
155	3	1	4.823
157	4	2	3.876
159	4	2	2.939
161	4	1	6.882
165	3	1	8.626
167	2	1	7.298
169	2	3	-
171	4	1	-
175	4	1	6.739
no number	4	1	3.173

Table iii.17 Data obtained from optical densitometry (mm equiv. Al. th.) of whole bones of Redcross Way femoral necks.

iii.18 Vertebral Body Optical Densitometry - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Vertebrae
2	1	1	-
6	4	1	5.034
9	3	1	-
11	4	1	2.548
24	2	2	2.952
26	4	2	-
28	4	2	2.509
32	4	2	2.093
34	u	3	-
44	4	3	3.655
46	1	1	3.993
48	4	2	-
52	4	2	-
54	2	1	5.073
56	3	2	4.396
60	4	1	4.956
62	4	1	2.158
64	4	2	-
72	4	2	-
89	2	2	4.110
91	4	1	2.561
92	u	3	-
96	2	2	3.069
99	2	2	-
100	4	2	3.004
101	3	2	4.058
114	4	1	-
116	3	2	2.509
118	3	2	1.910
119	4	1	3.355
120	u	3	-
122	4	2	-
136	1	2	5.047
137	2	1	4.474
140	2	2	4.696
150	4	2	2.653
155	3	1	3.030
157	4	2	2.405
159	4	2	2.321
161	4	1	2.848
165	3	1	4.904
167	2	1	3.824
169	2	3	-
171	4	1	-
175	4	1	4.136
no number	4	1	2.223

Table iii.18 Data obtained from optical densitometry of whole bones (mm equiv. Al. th.) from Redcross Way vertebral bodies.

iii.19 Radius Optical Densitometry - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Radii
2	1	1	-
6	4	1	3.966
9	3	1	3.707
11	4	1	4.162
24	2	2	2.770
26	4	2	2.496
28	4	2	2.574
32	4	2	1.780
34	u	3	-
44	4	3	3.745
46	1	1	4.058
48	4	2	1.780
52	4	2	2.665
54	2	1	4.643
56	3	2	-
60	4	1	4.344
62	4	1	-
64	4	2	-
72	4	2	2.262
89	2	2	2.743
91	4	1	-
92	u	3	-
96	2	2	-
99	2	2	-
100	4	2	3.186
101	3	2	-
114	4	1	-
116	3	2	-
118	3	2	1.910
119	4	1	3.355
120	u	3	-
122	4	2	-
136	1	2	5.047
137	2	1	4.474
140	2	2	4.696
150	4	2	2.653
155	3	1	3.030
157	4	2	2.405
159	4	2	2.321
161	4	1	2.848
165	3	1	4.904
167	2	1	3.824
169	2	3	-
171	4	1	-
175	4	1	4.136
no number	4	1	2.223

Table iii.19 Data obtained from optical densitometry (mm equiv. Al. th.) of whole bones from Redcross Way radius.

iii.20 Iliac Crest Optical Densitometry - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Ilia
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	2.119
24	2	2	3.277
26	4	2	-
28	4	2	2.522
32	4	2	1.872
34	u	3	-
44	4	3	-
46	1	1	2.874
48	4	2	-
52	4	2	-
54	2	1	2.563
56	3	2	2.405
60	4	1	-
62	4	1	2.379
64	4	2	-
72	4	2	-
89	2	2	3.55
91	4	1	2.288
92	u	3	-
96	2	2	2.964
99	2	2	-
100	4	2	3.069
101	3	2	2.873
114	4	1	6.374
116	3	2	2.184
118	3	2	-
119	4	1	-
120	u	3	-
122	4	2	-
136	1	2	3.576
137	2	1	3.954
140	2	2	2.965
150	4	2	5.606
155	3	1	3.017
157	4	2	-
159	4	2	-
161	4	1	-
165	3	1	3.629
167	2	1	2.627
169	2	3	-
171	4	1	-
175	4	1	4.513
no number	4	1	-

Table iii.20 Data obtained from optical densitometry of whole bones (mm equiv. Al. th.) from Redcross Way radius.

iii.21 Femoral Neck Bone Slice Optical Densitometry - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Femoral Neck
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	0.9084
24	2	2	0.3273
26	4	2	0.8649
28	4	2	0.7012
32	4	2	0.6440
34	u	3	-
44	4	3	-
46	1	1	1.2868
48	4	2	-
52	4	2	0.2132
54	2	1	0.9601
56	3	2	0.6501
60	4	1	1.0360
62	4	1	0.0495
64	4	2	-
72	4	2	0.3964
89	2	2	0.9099
91	4	1	0.2507
92	u	3	-
96	2	2	0.6156
99	2	2	-
100	4	2	1.1231
101	3	2	0.5631
114	4	1	0.2282
116	3	2	-
118	3	2	-
119	4	1	0.5916
120	u	3	-
122	4	2	-
136	1	2	0.8318
137	2	1	0.5976
140	2	2	1.5495
150	4	2	-
155	3	1	0.6967
157	4	2	0.4535
159	4	2	0.4519
161	4	1	0.4850
165	3	1	0.6742
167	2	1	0.7718
169	2	3	-
171	4	1	-
175	4	1	0.5459
no number	4	1	0.1840

Table iii.21 Data obtained from bone slice optical densitometry (mm equiv. Al. th.), of Redcross Way femoral necks.

iii.22 Vertebral Body Bone Slice Optical Densitometry - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Vertebral Bodies
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	0.848
24	2	2	0.543
26	4	2	-
28	4	2	0.534
32	4	2	-
34	u	3	-
44	4	3	0.516
46	1	1	0.703
48	4	2	-
52	4	2	-
54	2	1	0.974
56	3	2	0.937
60	4	1	0.925
62	4	1	0.540
64	4	2	-
72	4	2	-
89	2	2	0.955
91	4	1	0.689
64	u	3	-
96	2	2	0.625
99	2	2	-
100	4	2	0.604
101	3	2	-
114	4	1	-
116	3	2	0.877
118	3	2	0.471
119	4	1	0.829
120	u	3	-
122	4	2	-
136	1	2	1.426
137	2	1	-
140	2	2	-
150	4	2	0.598
155	3	1	0.656
157	4	2	-
159	4	2	0.688
161	4	1	0.516
165	3	1	0.842
167	2	1	0.745
171	2	3	-
169	4	1	-
175	4	1	0.961
no number	4	1	0.414

Table iii.22 Data obtained from bone slice optical densitometry (mm equiv. Al. th.), of Redcross Way vertebral bodies.

iii.23 Radius Bone Slice Optical Densitometry - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Radius
2	1	1	-
6	4	1	0.817
9	3	1	0.677
11	4	1	0.769
24	2	2	0.925
26	4	2	0.883
28	4	2	-
32	4	2	0.507
34	u	3	-
44	4	3	0.835
46	1	1	1.060
48	4	2	0.066
52	4	2	0.655
54	2	1	1.315
56	3	2	-
60	4	1	1.187
62	4	1	-
64	4	2	-
72	4	2	0.280
89	2	2	-
91	4	1	-
92	u	3	-
96	2	2	-
99	2	2	-
100	4	2	-
101	3	2	0.802
114	4	1	-
116	3	2	-
118	3	2	0.967
119	4	1	-
120	u	3	-
122	4	2	-
136	1	2	-
137	2	1	1.072
140	2	2	1.462
150	4	2	0.559
155	3	1	-
157	4	2	-
159	4	2	-
161	4	1	0.375
165	3	1	1.210
167	2	1	1.126
169	2	3	-
171	4	1	-
175	4	1	0.748
no number.	4	1	-

Table iii.23 Data obtained from bone slice optical densitometry (mm equiv. Al. th.), of Redcross Way radius.

iii.24 Iliac Crest Bone Slice Optical Densitometry - Redcross Way

Skel. No.	Age Score	Sex Score	Bone Mineral Density Iliac Crest
2	1	1	-
6	4	1	-
9	3	1	-
11	4	1	1.165
24	2	2	1.237
26	4	2	-
28	4	2	1.305
32	4	2	1.471
34	u	3	-
44	4	3	-
46	1	1	1.900
48	4	2	-
52	4	2	-
54	2	1	-
56	3	2	1.694
60	4	1	-
62	4	1	1.429
64	4	2	-
72	4	2	-
89	2	2	1.360
91	4	1	1.288
92	u	3	-
96	2	2	1.230
99	2	2	-
100	4	2	1.558
101	3	2	1.856
114	4	1	2.225
116	3	2	1.114
118	3	2	-
119	4	1	-
120	u	3	-
122	4	2	-
136	1	2	1.883
137	2	1	1.511
140	2	2	2.201
150	4	2	1.724
155	3	1	1.600
157	4	2	-
159	4	2	-
161	4	1	-
165	3	1	2.078
167	2	1	1.477
169	2	3	-
171	4	1	-
175	4	1	1.877
no number	4	1	-

Table iii.24 Data obtained from bone slice optical densitometry (mm equiv. Al. th.), of Redcross Way iliac crest.

iii.25 Femoral Cortical Thickness From Bone Slices

Skeleton no.	no.number	116	119	165	28	89	56	24
measur.1	0.102	0.106	0.079	0.133	0.058	0.164	0.178	0.099
measur.2	0.181	0.079	0.109	0.175	0.034	0.106	0.039	0.087
measur. 3	0.345	0.104	0.236	0.194	0.061	0.154	0.069	0.112
measur. 4	0.216	0.221	0.106	0.219	0.104	0.093	0.180	0.071
measur. 5	0.120	0.099	0.068	0.078	0.129	0.064	0.084	0.109
measur. 6	0.051	0.145	0.092	0.054	0.196	0.174	0.161	0.282
measur. 7	0.099	0.326	0.055	0.070	0.161	0.468	0.348	0.333
measur. 8	0.072	0.116	0.077	0.084	0.102	0.194	0.207	0.132
sum	1.186	1.196	0.822	1.007	0.845	1.417	1.266	1.225
mean	0.1482	0.1495	0.1027	0.1259	0.1056	0.1771	0.1583	0.1531
Skeleton no.	32	101	159	100	167	96	44	46
measur. 1	0.152	0.118	0.023	0.089	0.104	0.073	0.018	0.039
measur. 2	0.066	0.086	0.011	0.056	0.071	0.045	0.035	0.053
measur. 3	0.074	0.139	0.054	0.047	0.034	0.061	0.039	0.026
measur. 4	0.158	0.111	0.024	0.020	0.089	0.049	0.018	0.059
measur. 5	0.231	0.132	0.053	0.012	0.122	0.136	0.035	0.109
measur. 6	0.117	0.280	0.084	0.057	0.149	0.250	0.151	0.125
measur. 7	0.328	0.155	0.180	0.294	0.245	0.196	0.226	0.270
measur. 8	0.201	0.390	0.086	0.084	0.165	0.136	0.099	0.194
sum	1.327	1.411	0.515	0.659	0.979	0.946	0.621	0.875
mean	0.1659	0.1764	0.0644	0.0824	0.1224	0.1183	0.0776	0.1094
Skeleton no.	11	155	136	140	114	72	60	175
measur. 1	0.059	0.124	0.085	0.129	0.076	0.125	0.073	0.079
measur. 2	0.042	0.099	0.059	0.120	0.049	0.027	0.074	0.053
measur. 3	0.114	0.086	0.111	0.088	0.050	0.078	0.166	0.072
measur. 4	0.179	0.039	0.150	0.160	0.092	0.109	0.202	0.049
measur. 5	0.107	0.062	0.169	0.163	0.104	0.112	0.107	0.129
measur. 6	0.160	0.158	0.209	0.139	0.285	0.117	0.225	0.258
measur. 7	0.231	0.175	0.362	0.250	0.321	0.302	0.284	0.352
measur. 8	0.123	0.149	0.26	0.143	0.187	0.153	0.157	0.179
sum	1.015	0.892	1.405	1.192	1.164	1.023	1.288	1.171
mean	0.1269	0.1115	0.1756	0.1490	0.1455	0.1279	0.1610	0.1464

Skeleton no.	**161**	**137**	**62**	**52**	**26**	**91**	**54**	**157**
measur. 1	0.099	0.062	0.116	0.108	0.049	0.095	0.165	0.056
measur. 2	0.099	0.075	0.064	0.088	0.032	0.058	0.084	0.034
measur. 3	0.188	0.047	0.102	0.105	0.099	0.048	0.074	0.052
measur. 4	0.107	0.104	0.059	0.085	0.055	0.121	0.098	0.078
measur. 5	0.194	0.072	0.159	0.121	0.067	0.104	0.108	0.114
measur. 6	0.313	0.187	0.201	0.278	0.185	0.250	0.187	0.214
measur. 7	0.563	0.131	0.425	0.386	0.149	0.437	0.182	0.156
measur. 8	0.206	0.115	0.168	0.123	0.098	0.298	0.119	0.106
sum	1.769	0.793	1.294	1.294	0.734	1.411	1.017	0.810
mean	0.2211	0.0991	0.1618	0.1618	0.0918	0.1764	0.1271	0.1013

Table iii.25 The eight measurements recorded around the femoral neck and the mean thickness (cm).